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MIXING OPERATIONS ON A BITUMINIOUS EXPERIMENTAL ROAD IN SOUTH CAROLINA

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EXPERIMENTAL BITUMINOUS TREATMENT OF SANDY-SOIL ROADS

REPORT ON EXPERIMENTS IN SOUTH CAROLINA

Reported by PAUL F. CRITZ, Associate Highway Engineer, United States Bureau of Public Roads
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A BITUMINOUS experimental road was constructed in Horry County, S. C., in 1927. It is still in service, and the necessary maintenance has been such that the original construction has been preserved on about one-half of the project and the remainder has been modified only by the type of surface treatments applied.

The purpose of this experiment was to obtain information as to practicable methods of stabilizing the surfaces of roads built of the local materials characteristic of the southeastern coastal plain. Materials such as clays and mineral aggregates ordinarily considered satisfactory for stabilizing were not economically available and consequently bituminous materials were selected as the stabilizing agent.

At the time this road was built little information was available for the guidance of the engineers in the design of the sections and methods of construction. Since these experimental sections were built, however, considerable progress has been made in the field of low-cost bituminous road construction, and it is interesting to note that all of the materials and equipment and practically the same methods used in this experiment are in common use at the present time.

A better understanding of the methods and materials that give greater assurance of successful construction today has been made possible in a large measure by the information obtained from experimental roads. The fact that much of the road work done today by the State of South Carolina is based upon results obtained from this experiment indicates that it has been of considerable value.

ECONOMICAL METHOD OF STABILIZING SANDY SOILS NEEDED

Various methods of bituminous treatment to improve low-type roads have been employed by practically every State. Although many different materials and methods have been used, the improvements may be divided roughly into two classes: (1) The mat type of treatment, which is constructed not less than 1 inch thick; and (2) the surface-treatment type, in which the treatment is usually not more than 1 inch thick. Both types depend, as does any flexible surface, directly upon the base for support.

A wide variety of bituminous materials and aggregates have been used successfully for such work, and while different types of surfaces have resulted, there has been no special difficulty in providing a satisfactory surface for roads whose bases and subgrades were capable of supporting traffic.

For those localities where the roads were composed of loosely bound soil, such as sand or mixtures of sand, silt, and clay that were inherently weak, the problem of improvement was more difficult. Such a condition is found in the South Atlantic coastal area in general, and the eastern part of South Carolina in particular.

An appreciable mileage of the roads in this territory traverses relatively low, swampy areas that offer little opportunity for adequate drainage of the right-of-way because the ground-water level in many places is approximately at the elevation of the ground surface.

The locality these roads serve is mainly agricultural but pleasure resorts on the coast attract numbers of visitors. The traffic carried is variable in character and volume, ranging from fast-moving passenger cars to slow-moving, steel-tired vehicles carrying relatively heavy loads.

The soil composing these roads is predominantly sand containing clay and silt in varying proportions. As a rule no uniformity of composition exists, with the result that a satisfactory surface condition is the exception rather than the rule. The sand is composed of poorly graded, small-size particles. The clay possesses little binding power and slakes rapidly, breaking up in both wet and dry weather.

The combining of sand and clay produces a material which crumbles and becomes excessively dusty in dry weather. With continued dry weather traffic quickly cuts into the soil until the road becomes all but impassable. In wet weather water quickly softens the sand-clay and also causes the road to become almost impassable.

The stability of the surface, therefore, is as variable as the composition of the road material. On a given day the sandier portions might be extremely loose and difficult to travel over, while the portions containing some clay would be more stable but most likely would be very dusty. On the following day, if it had rained and the road was very moist, the sandier portions might present the better surface for traffic and the areas abounding in clay would be sloppy and rutted. Upon drying, these latter areas would regain some stability but the sandier portions would rapidly lose the stability provided by the moisture they had held temporarily. In all weather such surfaces are difficult to maintain in any condition approaching smoothness.

Obviously, the serviceability of a road of this kind is very limited and is not increased permanently by ordinary routine maintenance. In addition, the cost of maintenance under such conditions becomes an economic loss, especially when compared with the maintenance costs after the experimental surfaces were built. This later maintenance added to the permanent improvement of the road to such an extent that its cost in a large measure could be credited to betterment rather than to maintenance alone.

With a considerable mileage of such roads in need of immediate improvement, and with a relatively small amount of funds available for such work, South Carolina was confronted with a problem somewhat greater than existed in those States where the untreated roads were providing a satisfactory degree of serviceability and where it was necessary only to design a treatment that would either increase or make relatively permanent their present serviceability.

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VARIOUS TARS AND ASPHALTS USED ON SECTIONS OF EXPERIMENT

Experience has shown the suitability of sand as road surfacing material when mixed with a satisfactory binder. It is also recognized that sand, properly confined, has high bearing value irrespective of its grading. Consequently, the problem in South Carolina was that of so treating the sand or mixture of sand, silt, and inferior clay that advantage might be taken of these inherent qualities.

To develop a satisfactory and economical method of improving these loosely bonded, sand-clay roads, the South Carolina State Highway Department, in cooperation with the Bureau of Public Roads, constructed an experimental highway during 1927. This highway, 20.6 miles in length and approximately 20 feet wide, extends north and west from the northwest city limits of Conway, S. C., to Galivants Ferry, S. C. The road on which the experimental sections were built was typical of those of the Atlantic coastal area and, in general, was quite unsatisfactory as a highway. Portions of it, passing through low, swampy areas, were poorly drained. Throughout its length there existed combinations of sand and clay ranging from practically pure sand to mixtures fairly high in clay. Its behavior in wet and dry weather was typical of the loosely bound, sand-clay roads of this area whose behavior has already been described.

Part of the project lies on United States Highway No. 701 and all of it lies on United States Highway No. 501, which is an arterial highway to the coast. During the spring and summer months it carries both heavy and light, fast-moving traffic. During the crop-marketing seasons the main traffic is heavily loaded vehicles, a fair portion of which is on narrow steel tires.

The experimental road was constructed during the period from May to October 1927 and was divided into eight experiments, some of which were subdivided into sections. Bituminous mats were constructed on all sections; some were designed to serve as wearing surfaces and others to serve as bases to which additional surface treatments were applied. Some of the sections were designed for machine maintenance and others for maintenance such as is ordinarily applied to macadam-like surfaces. One experimental section, a double-application surface treatment laid directly upon the sand-clay soil, was included for comparison with the other experimental sections of the project and also with similar treatments successfully applied in other parts of the State where the roadbed soil was believed more suitable for such treatment. Locations and descriptions of the experimental sections are shown in figures 1, 2, 3, and 4, which also show the extent and character of the various re-treatments applied.

Both hot- and cold-application tars and asphalts were used in construction. The cold-application tars had consistencies of 8–13, 18–25, and 25–35 specific viscosity, Engler, at 40° C., and the hot-application tar had a float of 155 at 32° C. The tar of 8–13 viscosity was used to prime an untreated base preceding surface treatment; the tar of 18–25 viscosity was used as a binder in the mixed base and for the surface enrichment of the mix without the addition of a mineral cover; and the tar of 25–35 viscosity and the hot tar were used as binders with stone cover in the surface treatment of mixed bases.

Two types of the cold-application asphaltic materials were used—rapid-curing and slow-curing materials. The former were various grades of asphalt cements ranging in penetration from 85 to 180, cut back to low viscosity with a heavy naphtha distillate. The latter were slow-curing, liquid asphaltic materials produced by different processes of refining. Both the rapid- and slow-curing asphaltic materials were used as binders in the mixed bases and for surface treatment of the mixed bases. When used for surface treatment, the rapid-curing cutbacks were used with mineral aggregate cover while the slow-curing oils were used only for surface enrichment with no mineral cover material.

The hot-application material was an asphaltic cement and was used only in surface treatment with stone cover. All asphaltic materials came from a single refinery as did all tar products used in the experiments. Analyses of these materials are given in tables 1 and 2, with the exception of the slow-curing oil E and the 25–35 viscosity tar, analyses for which are not available. Amounts used in each section are given in figures 1, 2, 3, and 4.

Crushed granite, pea gravel, sand, and treated material bladed from the mixed mats were used as cover materials. The mechanical analyses of the stone, gravel, and sand are given in table 3.

BITUMINOUS MATS BUILT USING EXISTING ROAD MATERIALS

Prior to actual construction of the experimental sections, the road had received the customary routine maintenance but little had been done in the way of permanent improvement. Drainage structures had been installed where there was considerable run-off and slight fills and cuts had been made. In general the grade, with respect to the adjoining area, was low in comparison with standards of drainage and grade in use at the present time.

The stationing begins at Conway and, for the purpose of this report, the road may be considered as extending east and west. References to "east" or the "east end of an experiment" are therefore to be taken to mean the beginning of the experimental section or the end nearest Conway.

The initial step in constructing the mixed base was preparation of the roadbed soil for treatment. This involved scarifying to the depth desired and pulverizing the loosened material with disk harrows and blade graders. On some sections the soil was already in such a loose condition that the blade grader, without scarifying, readily converted it into a well pulverized mass. As the material was loosened, it was moved to the roadside into windrows until the amount necessary for the required thickness of mat had been accumulated and was then spread over the full width of the road.

After the material was evenly distributed, usually in half-mile units, bituminous material was applied with 600-gallon pressure distributors. The total amount of bitumen was spread in two or more applications, and after each application a disc harrow turned the mixture of bitumen and soil. The object of this preliminary mixing was to prevent the early loss of light constituents of the bitumen, to protect passing traffic, and to prevent the accumulation of pools of bitumen in depressions and wheel tracks.

Final mixing was done by power-drawn graders which bladed the mixture back and forth across the road until it presented a homogeneous appearance. Because of varying composition and grading of the soil, some portions of the unit under construction might appear too lean or too rich. Additional bitumen or soil was worked into such portions until they appeared satis-

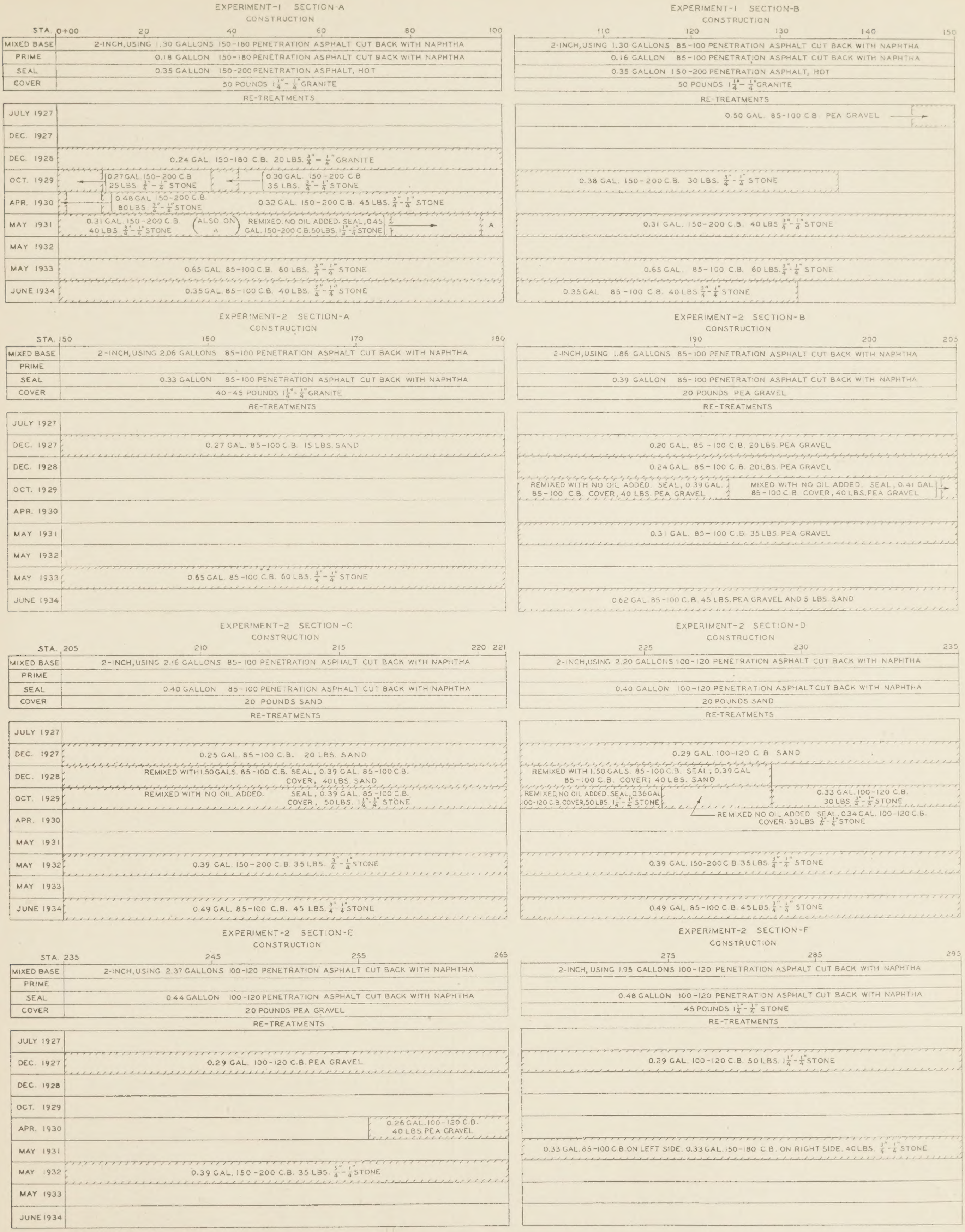


FIGURE 1.—CHART SHOWING CONSTRUCTION AND CHARACTER OF RE-TREATMENTS APPLIED TO EXPERIMENTAL SECTIONS 1 TO 2-F, INCLUSIVE.

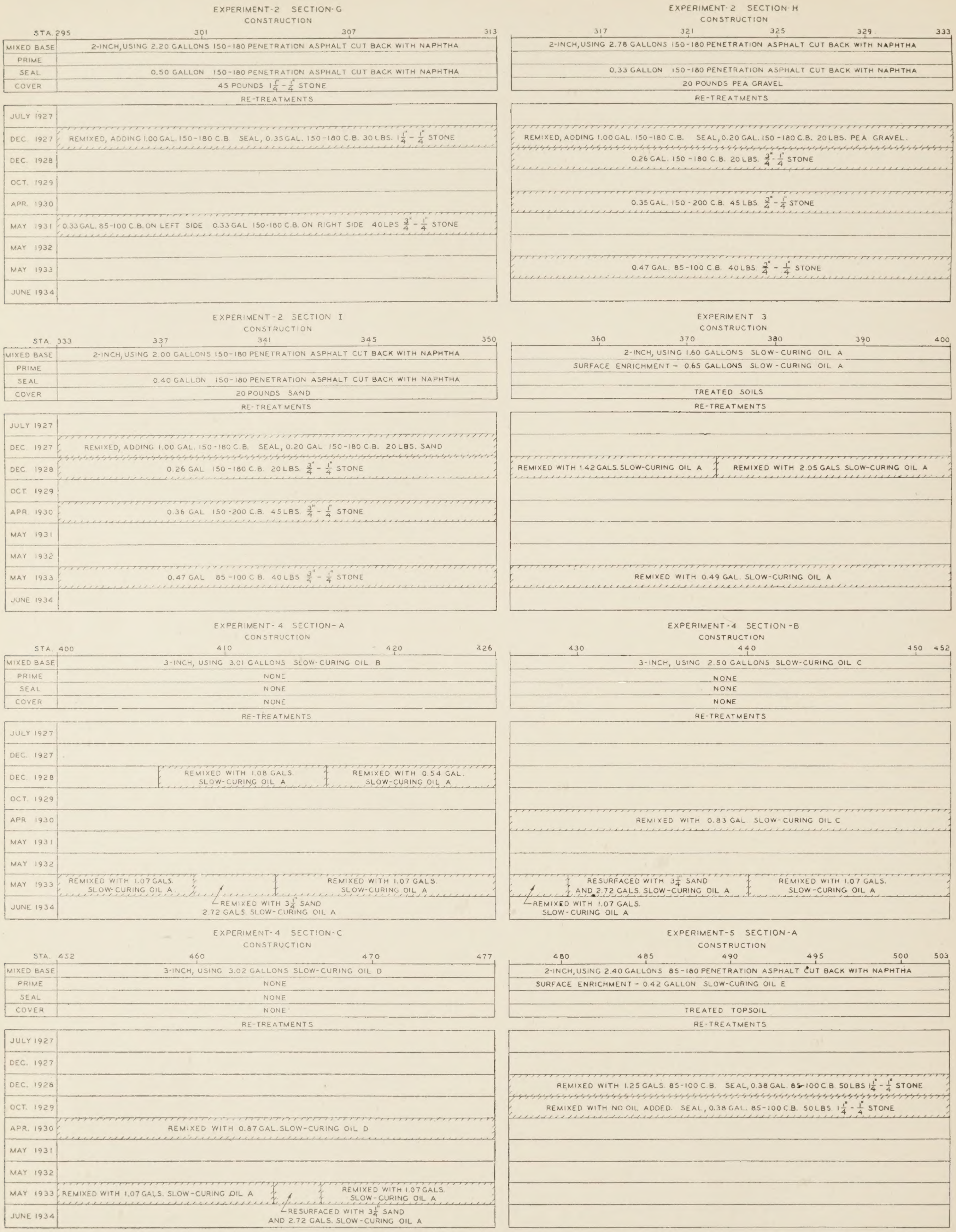


FIGURE 2.—CHART SHOWING CONSTRUCTION AND CHARACTER OF RE-TREATMENTS APPLIED TO EXPERIMENTAL SECTIONS 2–G TO 5–A, INCLUSIVE.

EXPERIMENT-5 SECTION-B

CONSTRUCTION

STA.	503 512 521 530
MIXED BASE	2-INCH, USING 2.20 GALLONS 85-100 PENETRATION ASPHALT CUT BACK WITH NAPHTHA
PRIME	SURFACE ENRICHMENT-0.40 GALLON 150-180 PENETRATION ASPHALT CUT BACK WITH NAPHTHA
SEAL	
COVER	TREATED TOPSOIL

RE-TREATMENTS

JULY 1927	
DEC. 1927	
DEC. 1928	
OCT. 1929	
APR. 1930	
MAY 1931	
MAY 1932	
MAY 1933	0.46 GAL. 85-100 C.B. 40 LBS. $\frac{3}{4}$"-$\frac{1}{4}$" STONE
JUNE 1934	

EXPERIMENT-5 SECTION-C

CONSTRUCTION

STA.	540 550 556
MIXED BASE	3-INCH, USING 2.90 GALLONS 85-100 PENETRATION ASPHALT CUT BACK WITH NAPHTHA
PRIME	SURFACE ENRICHMENT- 0.42 GALLON 150-180 PENETRATION ASPHALT CUT BACK WITH NAPHTHA
SEAL	
COVER	TREATED TOPSOIL

RE-TREATMENTS

JULY 1927	
DEC. 1927	
DEC. 1928	
OCT. 1929	
APR. 1930	
MAY 1931	
MAY 1932	
MAY 1933	0.46 GAL. 85-100 C.B. 40 LBS. $\frac{3}{4}$"-$\frac{1}{4}$" STONE
JUNE 1934	

EXPERIMENT-5 SECTION-D

CONSTRUCTION

STA.	556 560 570 580 582
MIXED BASE	3-INCH, USING 3.01 GALLONS 85-100 PENETRATION ASPHALT CUT BACK WITH NAPHTHA
PRIME	SURFACE ENRICHMENT- 0.42 GALLON SLOW CURING OIL E
SEAL	
COVER	TREATED TOPSOIL

RE-TREATMENTS

JULY 1927	
DEC. 1927	
DEC. 1928	
OCT 1929	0.39 GAL. 85-100 C.B. 40 LBS. $\frac{3}{4}$"-$\frac{1}{4}$" STONE
APR. 1930	
MAY 1931	
MAY 1932	
MAY 1933	0.46 GAL. 85-100 C.B. 40 LBS. $\frac{3}{4}$"-$\frac{1}{4}$" STONE
JUNE 1934	

EXPERIMENT-6 SECTION-A

CONSTRUCTION

STA.	590 600 610
MIXED BASE	2-INCH, USING 2.72 GALLONS 18-25 SPECIFIC VISCOSITY TAR
PRIME	SURFACE ENRICHMENT — 0.27 GALLON 18-25 SPECIFIC VISCOSITY TAR
SEAL	
COVER	TREATED TOPSOIL

RE-TREATMENTS

JULY 1927	
DEC. 1927	
DEC. 1928	
OCT 1929	
APR. 1930	
MAY 1931	0.36 GAL. 35-50 SP. VIS. TAR 37 LBS. $\frac{3}{4}$"-$\frac{1}{4}$" STONE
MAY 1932	
MAY 1933	
JUNE 1934	

EXPERIMENT-6 SECTION-B

CONSTRUCTION

STA.	610 620 630 636
MIXED BASE	3-INCH, USING 3.72 GALLONS 18-25 SPECIFIC VISCOSITY TAR
PRIME	SURFACE ENRICHMENT — 0.28 GALLON 18-25 SPECIFIC VISCOSITY TAR
SEAL	
COVER	TREATED TOPSOIL

RE-TREATMENTS

JULY 1927	
DEC 1927	
DEC. 1928	
OCT. 1929	
APR. 1930	
MAY 1931	0.36 GAL. 35-50 SP. VIS. TAR, 37 LBS. $\frac{3}{4}$"-$\frac{1}{4}$" STONE
MAY 1932	
MAY 1933	
JUNE 1934	

EXPERIMENT-6 SECTION-C

CONSTRUCTION

STA.	640 660 680 688
MIXED BASE	2-INCH, USING 2.75 GALLONS 18-25 SPECIFIC VISCOSITY TAR
PRIME	0.26 GALLON 18-25 SPECIFIC VISCOSITY TAR
SEAL	0.37 GALLON 25-35 SPECIFIC VISCOSITY TAR
COVER	60 POUNDS $1\frac{1}{4}$"-$\frac{1}{4}$" STONE

RE-TREATMENTS

JULY 1927	
DEC 1927	
DEC. 1928	
OCT. 1929	
APR. 1930	
MAY 1931	0.36 GAL. 35-50 SP. VIS. TAR, 37 LBS. $\frac{3}{4}$"-$\frac{1}{4}$" STONE
MAY 1932	
MAY 1933	
JUNE 1934	

EXPERIMENT-6 SECTION-D

CONSTRUCTION

STA.	688 690 700 710 720 730 742
MIXED BASE	2-INCH, USING 2.59 GALLONS 18-25 SPECIFIC VISCOSITY TAR
PRIME	0.27 GALLON 18-25 SPECIFIC VISCOSITY TAR
SEAL	0.35 GALLON HOT TAR (GRADE 2)
COVER	60 POUNDS $1\frac{1}{4}$"-$\frac{1}{4}$" STONE

RE-TREATMENTS

JULY 1927	
DEC. 1927	
DEC. 1928	
OCT. 1929	
APR. 1930	
MAY 1931	0.36 GAL. 35-50 SP. VIS. TAR, 37 LBS. $\frac{3}{4}$"-$\frac{1}{4}$" STONE
MAY 1932	
MAY 1933	
JUNE 1934	

EXPERIMENT-6 SECTION-E

CONSTRUCTION

STA.	750 760 770 780 790 794
MIXED BASE	2-INCH, USING 18-25 SPECIFIC VISCOSITY TAR, GALLONS PER SQUARE YARD AS FOLLOWS: 1.77 — 2.51 — 2.93 — 2.08
PRIME	0.25 GALLON 18-25 SPECIFIC VISCOSITY TAR
SEAL	0.32 GALLON HOT TAR (GRADE 2)
COVER	60 POUNDS $1\frac{1}{4}$"-$\frac{1}{4}$" STONE

RE-TREATMENTS

JULY 1927	
DEC. 1927	
DEC. 1928	
OCT. 1929	
APR. 1930	
MAY 1931	0.36 GAL. 35-50 SP. VIS. TAR, 37 LBS. $\frac{3}{4}$"-$\frac{1}{4}$" STONE
MAY 1932	
MAY 1933	
JUNE 1934	

FIGURE 3.—CHART SHOWING CONSTRUCTION AND CHARACTER OF RE-TREATMENTS APPLIED TO EXPERIMENTAL SECTIONS 5–B TO 6–E, INCLUSIVE.

TABLE 1.—*Analyses of asphaltic materials used in construction and re-treatment*[1]

Type of material	Slow-curing oils							Asphalts of the penetration given, cut back with naphtha																Asphaltic cement
Designation	A[2]				B[3]	C[3]	D[3]	85-100 penetration							100-120 penetration		150-180 penetration					150-200 penetration		150-200 penetration
Laboratory number	29143	29147	30994	39068	29148	29743	29746	9 tests	29883	30993	32643	32645	35426	39069	29144	32644	29088	29145	29882	30992	35425	32646	35424	4 tests
Method of use	Construction	Construction	Re-treatment	Re-treatment	Construction	Construction	Construction	Construction	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Construction	Re-treatment	Construction	Construction	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Construction
Date used	1927	1927	1928	1933	1927	1927	1927	1927	1927	1928	1929	1929	1931	1933	1927	1929	1927	1927	1927	1928	1931	1929	1931	1927
Sections on which used	3	3	3, 4-A	3, 4-A, B, C	4-A	4-B	4-C	1-B, 2-A, B, C, 5, 7, 8	1-B, 2-A, B, C, 8	2-B, C, D, 5-A	2-B, C	5-A, D, 7-B, C	2-B, F, G, 7-A, B, C, 8	1-A, B, 2-A, H, I, 5-B, C, D	2-D, E, F	2-D	1-A, 2-G, 5-B,	2-H, I, 5-C	2-G, H, I	1-A, 2-H, I	2-F, G	1-A, B, 8	1-A, B	1-A, B, 7-A, B, 8
Purposes for which used	Mix and surface enrichment	Mix and surface enrichment	Remix	Remix	Mix	Mix	Mix	Mix, prime, and surface treatment	Surface treatment	Remix and surface treatment	Surface treatment	Surface treatment	Surface treatment	Surface treatment	Mix and surface treatment	Surface treatment	Mix and surface treatment	Mix and surface treatment	Remix and surface treatment	Surface treatment	Surface treatment	Surface treatment	Surface treatment	Surface treatment
Analyses:																								
Specific gravity, 25°/25° C	0.942	0.941	0.972	1.012	1.025	1.028	0.974	0.941-0.950	0.949	0.938	0.953	0.944	0.955	0.948	0.957	0.949	0.952	0.956	0.959	0.938	0.949	0.949	0.950	1.01-1.03
Flash point ° C	110	115	125	127	105	127	132	25-52	29	29	32	30	27	29.5	50	31	54	35	30	28		29	23.2	225-275
Burning point ° C	150	165			145	149	172	27-60	40	30	36	35			60	37	65	40	50	30				
Specific viscosity, Engler, at 25° C	124	133			134			68-112	137						432		156	186	150					
Specific viscosity, Engler, at 40° C	33	40	138	69	36	41	48	25-48	36	39	88	52		88	105	72	45	57	45	40		56		
Specific viscosity, Engler, at 50° C			74						[4] 3	21	52	31	70	44		37			[4] 4	23	28	30	32	
Penetration, 25° C., 100 grams, 5 seconds																								167-186
Softening point ° C																								39-43
Loss, 163° C., 5 hours, 20 grams percent	8.2	8.1	9.1	7.0	10.7	11.0	9.5	27.8-33.9	29.0	25.3	23.6	24.7	21.5	24.3	24.6	23.8	26.5	29.6	22.7	26.3	24.2	24.7	24.3	
Residue float at 32°C seconds			115			157	53																	
Residue float at 50°C seconds				22	25	57	24																	
Residue penetration at 25° C								56-98	51	75	75	69	66	51	77	77	79	58	140	62	102	95	102	
Loss, 163° C., 5 hours, 50 grams percent	5.5	5.6	5.6	4.7	6.6	7.1	6.6	25.5-32.0	26.7	24.2	22.4	23.6	20.8	23.2	21.8	22.7	24.3	27.1	20.6	25.2	23.4	23.7	23.4	0.13-0.34
Residue float at 32° C seconds						31	22																	
Residue float at 50° C seconds				19		21	12																	
Residue penetration at 25° C								130-288	128	145	134	124	100	91	176	136	170	135	280	95	176		177	130-141
Bitumen soluble in CS_2 percent	99.76	100	100	99.94	100	99.78	99.81	99.87-100	99.86	100	99.85	99.90	99.91	99.86	100	99.87	100	100	99.85	100	99.86	99.85	99.85	99.91-99.80
Organic matter insoluble percent	.00	0	0	.06	0	.18	.19	.0-.10	.14	0	.14	.08	.06	.14	0	.07	0	0	.15	0	.13	.09	.14	0.09-0.20
Inorganic matter insoluble percent	.24	0	0	.00	0	.04	.00	.0-.03	.00	0	.01	.02	.03	.00	0	.06	0	0	.00	0	.01	.06	.01	0.00-0.00
Bitumen insoluble in CCl_4 percent				.05																				
Bitumen insoluble in 86° B. naphtha percent	5.3	5.3	12.8	8.4	13.9	14.2	10.0	16.0-18.4	19.7	15.8	15.1	16.0	17.8	17.0	18.3	15.2	17.4	20.4	18.7	17.6	14.4	13.9	13.8	20.3-25.5
Residue of 100 penetration percent	59	58	70	61	66	69	61	66-72	71	75	76	75			75	76	73	71	75	73		74		97-99
Softening point of residue ° C	52	53	45	42	45	43	54	45-55	55	48	48	48			49	47	50	57	50	55		44		44-47
Ductility of residue at 25° C centimeters	42	32	110+	110+	110+	60	8	14-110+	11	52	110+	110+			110+	110+	17	19	110+	9		110+		110+
Distillation by volume, D20-30 modified[5]:																								
Total distillate to 190° C. (374° F.) percent											5.4	7.5				4.2						2.3		
Total distillate to 225° C. (437° F.) percent											17.5	21.9				17.8						16.2		
Total distillate to 360° C. (680° F.) percent											29.3	32.8				29.5						30.4		
Residue—Softening point ° C											45.8	49.6				45.0						41.8		
Residue—Penetration at 25° C											90	98				98						183		
Distillation by volume, cooperative method[5]:																								
Total distallate to 437° F percent													14.2	20.0							16.6		16.8	
Total distallate to 600° F percent													23.7	26.5							26.4		26.3	
Total distillate to 680° F percent													25.0	28.5							28.5		28.4	
Residue—Penetration at 25° C													96	85							169		166	
Residue—Ductility at 25° C centimeters													110+	110+							110+		110+	
Residue—Solubility in CS_2 percent													99.82	99.72							99.85		99.85	

[1] Analyses of the 100-120 cut-back used in the 1927 re-treatments and of materials used in the re-treatments of 1930, 1932, and 1934 are not available, but were similar in characteristics to those used in former and later re-treatments as they were purchased under the same specifications. Analyses are not available for slow-curing oil F, used in 1927 in surface enrichment of sections 5-A and 5-D during construction.

[2] Straight reduced.

[3] Pressure still or cracked asphaltic material.

[4] Specific viscosity, Engler, at 100° C.

[5] Thermometer bulb ¼ inch from bottom of flask Residue poured immediately upon reaching maximum temperature.

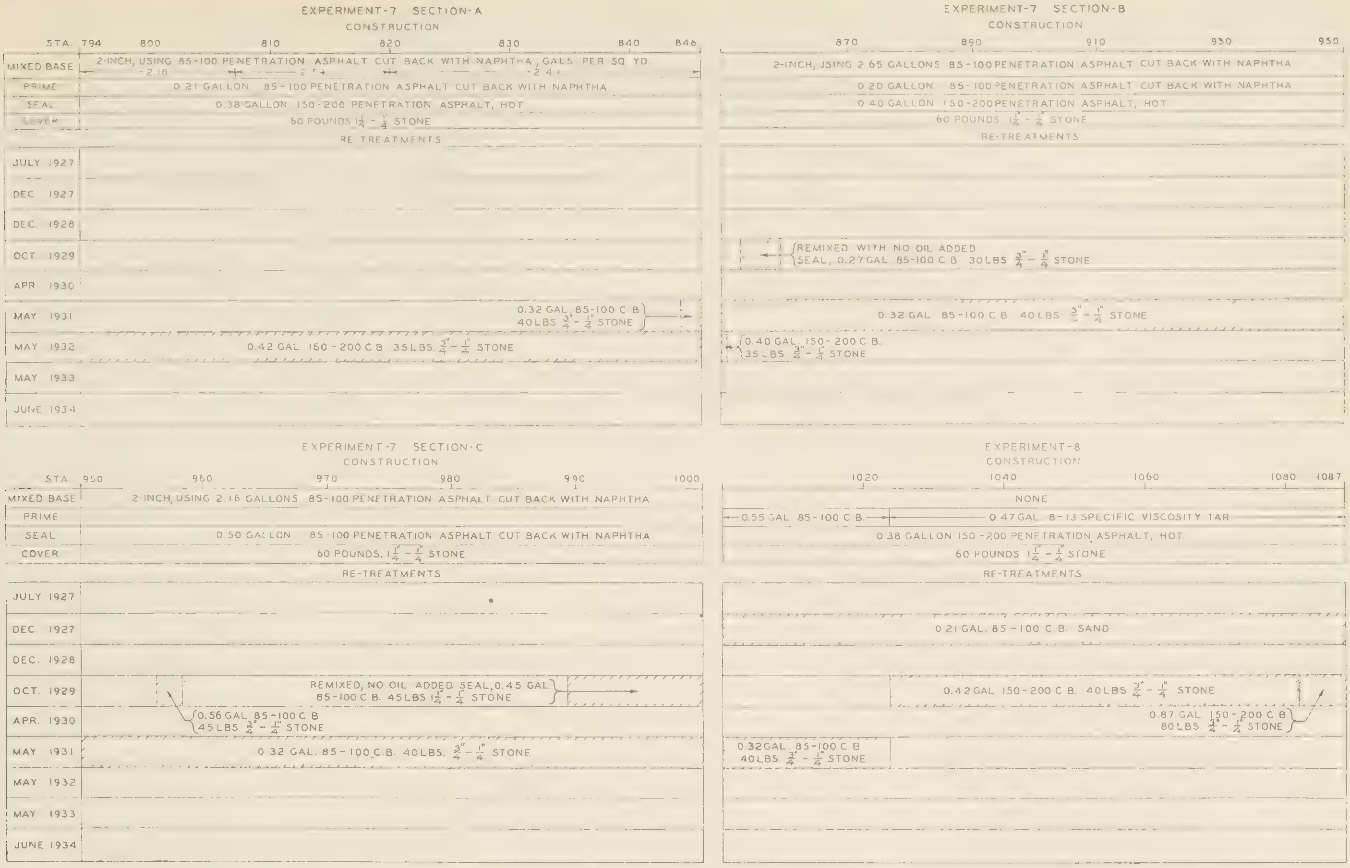


FIGURE 4.—CHART SHOWING CONSTRUCTION AND CHARACTER OF RE-TREATMENTS APPLIED TO EXPERIMENTAL SECTIONS 7–A TO 8, INCLUSIVE.

TABLE 2.—*Analyses of tars used in construction and re-treatment* [1]

Method of use	Construction					Re-treatment
Date used	1927					1931
Material designation	8–13 viscosity	18–25 viscosity			Grade 2 (hot)	35–50 viscosity
Section and purpose for which used: Base mix		6–A, B, C, D, E				
Prime	8	6–C, D, E				
Surface treatment		6–A, B			6–D, E	
Re-treatment						6–A, B, C, D, E
Laboratory no	29828	Minimum values	Maximum values	Average of 6	29753	36043
Analyses:						
Specific gravity, 25°/25° C	1.136	1.152	1.165	1.158	1.206	1.151
Specific viscosity, Engler, at 40° C	10.9	19.3	26.4	22.3		48.7
Float test at 32° C, seconds					155	
Bitumen soluble in CS_2, percent	94.63	93.39	95.76	95.14	91.51	96.08
Organic matter insoluble, percent	3.80	2.66	4.85	3.17	8.49	3.69
Inorganic matter insoluble, percent	.07	0	.06	.02	0	.23
Water, percent	1.50	1.50	1.80	1.67	0	0
Distillation, A. S. T. M. D20-27T (by weight)—						
–170° C, percent	1.32	.89	1.15	1.02	0	.37
170°–235° C, percent	5.68	6.10	8.74	7.44	3.35	4.82
235°–270° C, percent	13.30	10.10	11.16	10.64	6.10	10.54
270°–300° C, percent	9.94	7.39	8.53	7.86	6.16	8.91
Residue, percent	69.12	71.44	73.63	72.61	83.95	75.20
Softening point of residue, ° C	39.6	45.8	49.9	47.6	49.5	37.4

[1] Data are not available for the tar of 25–35 viscosity used in surface-treating section 6–C.

TABLE 3.—*Mechanical analysis of mineral aggregates used as cover material*

Experiment no.	2	2	1, 2, 6, 7, 8	8
Material	Pea gravel	Sand	Granite	Granite
Laboratory no.	29558	29557	29630	29631
Retained on—	*Percent*	*Percent*	*Percent*	*Percent*
1¼-inch screen			4	
1-inch screen			33	2
¾-inch screen			73	35
½-inch screen	1		92	68
¼-inch screen	7		98	92
No. 10 sieve	41	4		
No. 20 sieve	61	29		
No. 30 sieve	70	52		
No. 40 sieve	81	74		
No. 50 sieve	87	79		
No. 80 sieve	92	85		
No. 100 sieve	93	88		
No. 200 sieve	96	94		

factory, after which the mixture was respread uniformly for compaction under traffic. Light blading was continued during compaction to obtain a smooth surface. Some difficulty was experienced in obtaining uniform distribution of traffic during this stage. Fast-moving vehicles tended to travel in the center only and slow-moving, steel-tired vehicles traveled along the edges where the wheels cut into the mixture instead of compacting it. Barriers first placed in the center of the road and then moved transversely at intervals successfully divided traffic into two lanes, causing more uniform compaction of each half of the road.

For the two sections designed for machine maintenance, this concluded the construction operation except for occasional light blading to retain surface smoothness. The analyses of the sand-clay and the resulting bituminous mixtures are given in tables 4 and 5.

AMOUNTS OF BITUMINOUS MATERIALS NEEDED IN MIXTURES WERE ESTIMATED

The remainder of the experimental sections were designed for patrol maintenance and were provided with wear-resisting surfaces obtained by two methods. One method was to enrich the surface portion of the mixed base by a light application of bitumen covered immediately with bituminous-treated soil previously windrowed to the sides of the road. The other method was to surface-treat the mixed base with bitumen and aggregate cover. This surface treatment was placed after allowing the base a period of time in which to become firm and smooth; the actual time varied from 3 or 4 days to a month. On those sections on which the bitumen used in the surface treatment was a cold-application, low-viscosity material, the bitumen was applied directly upon the smooth, compacted, mixed base and covered immediately with the selected mineral cover material. Where the binding material was a hot application or a fairly viscous cold-application bitumen such as the 25–35 viscosity tar, the mixed base was given a light prime with the same type of bituminous material that was used in the mixed base.

The mineral cover material was spread by hand from piles along the roadside and was hand broomed to obtain uniform distribution. Following its application the surfaces were rolled with 5-ton, three-wheel rollers.

After a few days under traffic, the completed sections varied in appearance, depending upon the air temperature and the materials used. All of the tar sections

TABLE 4.—*Analysis of road-bed soil used in mixed base construction and as the base for surface treatment of experiment 8. All are group A–2 or A–3 materials*

Experiment no.	Stations represented by sample	Laboratory no.	Mechanical analysis: Coarse sand 2.0–0.25 mm	Mechanical analysis: Fine sand 0.25–0.05 mm	Mechanical analysis: Silt 0.05–0.005 mm	Mechanical analysis: Clay 0.005 mm	Remarks
			Pct.	*Pct.*	*Pct.*	*Pct.*	
1–A	7–12	2884	17	70	6	7	Sandier portion of section.
	18	2885	14	65	9	12	Average composition.
1–B	115	3140	29	56	6	9	Do.
2–D	228	3143	21	52	8	19	Clay area.
2–F	290	3141	16	75	3	6	Sandy area.
2–G	310	3142	9	82	2	7	Do.
5–B	515–520	3515	6	86	2	6	Do.
	503–530	3517	5	88	2	5	Average composition.
5–C	530–556	3516	4	77	9	10	Do.
6–A	582–610	3684	5	75	8	12	Do.
6–B	610–636	3685	8	67	13	12	Do.
6–C	636–688	3686	5	66	16	13	Do.
6–D	688–742	3687	4	75	9	12	Do.
6–E	742–755	3676	4	80	8	8	Do.
	755–768	3677	4	80	6	10	Do.
	762–767	3568	8	70	8	14	Do.
	768–781	3678	4	82	6	8	Do.
	781–794	3679	4	84	5	7	Do.
7–A	794–807	3680	5	81	5	9	Do.
	807–820	3681	5	81	6	8	Do.
	820–833	3682	5	78	5	12	Do.
	833–846	3683	6	77	7	10	Do.
7–B	846–872	3567	6	76	4	14	Do.
	872–898	3688	4	86	5	5	Do.
	898–924	3689	4	85	4	7	Do.
	924–950	3569	8	77	5	10	Do.
7–C	950–975	3572	10	71	9	10	Do.
	975–1000	3573	13	69	6	12	Do.
8	1000–1025	3574	26	58	6	10	Do.
	1015–1020	3575	19	68	6	7	Do.
	1025–1050	3576	36	42	12	10	Do.
	1050–1087	3577	45	38	11	6	Do.
Average			11	73	7	9	

bled freely from the start and within a few days gave the appearance of having been in service for some time. The sections on which hot asphalt was used did not bleed so markedly and retained a loose, uncompacted appearance for a longer period. One exception was the first experiment, where less cover stone was used and so much bleeding occurred that additional cover stone was required to prevent the mat from picking up under traffic. The cold-application asphalt, which was a cut-back material, readily coated the stone cover which took on a dark appearance within a few hours.

Experiment 8 was a double surface treatment applied directly to the untreated soil surface. The roadbed soil of this section, like that of the others, varied considerably in composition and degree of bond. Prior to applying the treatment the surface was swept to remove excess loose material. Depressions were filled with stone before the bitumen was applied. The prime was applied and allowed to dry for 4 to 6 days during which time traffic was detoured. The hot-application material was then spread, immediately covered with crushed stone, and lightly rolled.

In planning the experiments, the amounts of bituminous materials believed necessary were estimated, as little information upon which to design the mixtures was available at the time. During the initial construction it became apparent that the estimated quantities were too low and they were increased. The quantity used varied with the character of the soil encountered in the different sections. In sections 6–E and 7–A, however, the amounts used were varied intentionally to study the effect of such variation on service behavior.

No particular difficulty was encountered in the mixing operation. All of the bituminous materials were

TABLE 5.—*Analyses of bituminous mixtures used as bases and surface mats, sampled during or immediately after construction*

Section	Stations represented	Laboratory no.	Bituminous material	Composition by weight											Appearance of the mixture
				Bitumen	Passing ½ inch, retained ¼ inch	Passing ¼ inch, retained No. 10	Passing No. 10, retained No. 20	Passing No. 20, retained No. 30	Passing No. 30, retained No. 40	Passing No. 40, retained No. 50	Passing No. 50, retained No. 80	Passing No. 80, retained No. 100	Passing No. 100, retained No. 200	Passing No. 200	
				Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
1-A	70	29089	Asphalt, 150-180 penetration cut-back [1]	3.8	1.7	11.5	15.7	9.4	7.4	5.9	11.0	5.6	11.1	16.9	Poorly bonded.
1-B	115	29086	Asphalt, 85-100 penetration, cut-back [1]	4.0		.3	4.0	3.1	5.1	11.5	32.0	12.0	18.0	10.0	Do.
2-C	213	29836	do	5.5	11.7	3.4	4.9	5.2	7.4	8.2	21.0	7.4	11.4	13.9	Do.
	205-220	29111	do	3.8		2.7	6.4	3.8	6.5	9.8	29.0	11.0	12.8	14.2	Do.
2-D	228	29114	Asphalt, 100-120 penetration, cut-back [1]	3.8		1.2	3.2	3.3	5.7	9.1	29.7	14.0	17.9	12.1	Do.
2-G	300	29113	Asphalt, 150-180 penetration, cut-back [1]	2.8		1.1	1.7	1.2	1.7	2.1	32.0	31.0	14.0	12.4	Do.
2-H	327	29761	do	4.2		.4	1.4	1.6	2.4	3.2	35.6	24.0	16.0	11.2	Do.
2-I	344	29112	do	4.6		.4	2.2	2.3	3.3	3.3	13.9	20.5	39.9	9.6	Do.
4-A	400-426	29155	Slow-curing oil B [2]	7.1	2.0	1.6	2.0	1.2	1.2	1.6	22.8	19.6	28.4	12.5	Satisfactory.
4-B	426-452	29156	Slow-curing oil C [2]	7.6		.4	.8	1.2	2.0	2.4	33.6	21.6	21.2	9.2	Do.
5-B	515-520	29149	Asphalt, 85-100 penetration, cut-back [1]	3.1		.6	.6	.4	.9	1.2	19.8	34.9	32.4	6.1	Poorly bonded.
	503-530	29150	do	2.8		.8	1.2	.6	.8	1.4	23.1	24.9	34.0	10.4	Do.
5-C	530-556	29151	do	4.9		2.8	2.8	1.4	1.4	1.2	21.0	11.4	30.7	22.4	Do.
6-A	582-610	29812	Tar, 18-25 specific viscosity [3]	5.2	.8	1.2	1.6	1.2	2.4	3.2	28.4	22.8	22.0	11.2	Do.
6-B	610-636	29811	do	6.2	5.6	3.6	2.8	2.0	3.6	2.4	44.4	4.0	21.2	4.2	Rich.
6-C	636-688	29810	do	5.0	2.0	2.6	2.6	1.6	2.4	3.2	35.2	15.2	18.4	11.8	Well bonded.
6-D	688-742	29809	do	7.1	2.0	1.4	1.6	1.6	2.8	3.2	24.8	18.8	25.6	11.1	Do.
6-E	742-755	29808	do	5.2	.8	1.6	1.8	1.2	2.0	2.4	19.0	30.6	25.2	10.2	Lean.
	755-768	29728	do	7.6		1.5	2.0	.7	1.0	2.0	10.0	24.0	32.0	19.2	Well bonded.
	768-781	29807	do	8.0	4.0	1.6	1.2	1.0	2.0	2.4	19.6	21.6	28.0	10.6	Rich.
	781-794	29806	do	7.2	3.2	1.6	1.4	.8	1.4	1.8	37.2	42.0	.8	2.6	Well bonded.
7-A	794-807	29762	Asphalt, 85-100 penetration, cut back [1]	5.2		1.6	1.6	1.2	1.4	1.8	19.4	26.0	31.4	10.4	Lean. Remixed with additional bitumen.
	794-807	29772	do	7.4	.4	.8	1.6	1.2	1.6	2.0	16.0	35.6	19.2	14.2	Well bonded after remixing.
	807-820	29763	do	5.5		1.0	.8	.8	1.3	2.0	33.6	15.7	30.4	8.9	Lean. Remixed with additional bitumen.
	807-820	29773	do	6.7	.4	.4	.8	.6	1.4	2.0	25.6	38.7	14.8	8.6	Well bonded after remixing.
	820-833	29788	do	6.7	1.2	.8	1.4	.8	1.6	2.0	23.0	28.4	25.2	8.9	Well bonded.
	833-846	29789	do	6.6	1.4	.8	1.6	1.4	1.4	2.0	17.2	42.0	8.4	17.2	Do.
7-B	846-872	29732	do	6.7	.6	.4	.8	.4	1.0	1.6	22.2	21.2	32.4	12.7	Do.
	872-898	29733	do	6.7	2.4	2.2	2.2	.8	.8	1.4	14.8	20.0	34.0	14.7	Do.
	898-924	29770	do	6.6	1.4	1.4	1.4	1.2	1.4	1.6	10.0	22.0	40.8	12.2	Do.
	924-950	29771	do	5.2	.4	.8	1.0	.8	1.6	2.2	15.6	30.8	31.0	10.6	Do.
7-C	950-963	29790	do	6.2	2.8	2.8	2.8	1.6	2.2	2.8	18.4	36.0	9.6	14.8	Do.
	963-975	29791	do	5.7	1.6	2.0	2.6	1.6	2.2	2.8	19.2	38.0	11.2	13.1	Do.
	975-987	29786	do	4.7	.4	2.6	4.0	2.4	2.8	3.6	54.0	1.6	10.6	13.3	Do.
	987-1000	29787	do	4.9	8.8	4.0	3.6	2.2	2.8	3.6	16.0	16.4	22.6	15.1	Do.
			Range of values: Maximum	8.0	11.7	11.5	15.7	9.4	7.4	11.5	54.0	42.0	40.8	22.4	
			Range of values: Minimum	2.8	0	.3	.6	.4	.8	1.2	10.0	1.6	.8	2.6	
			Range of values: Average [4]	5.6	1.7	1.9	2.6	1.8	2.5	3.3	24.1	22.7	21.8	12.0	

[1] Asphalt of the penetration given was cut back with naphtha.
[2] Pressure-still or cracked material.
[3] Engler specific viscosity at 40° C.
[4] Data for samples 29762 and 29763 excluded from averages.

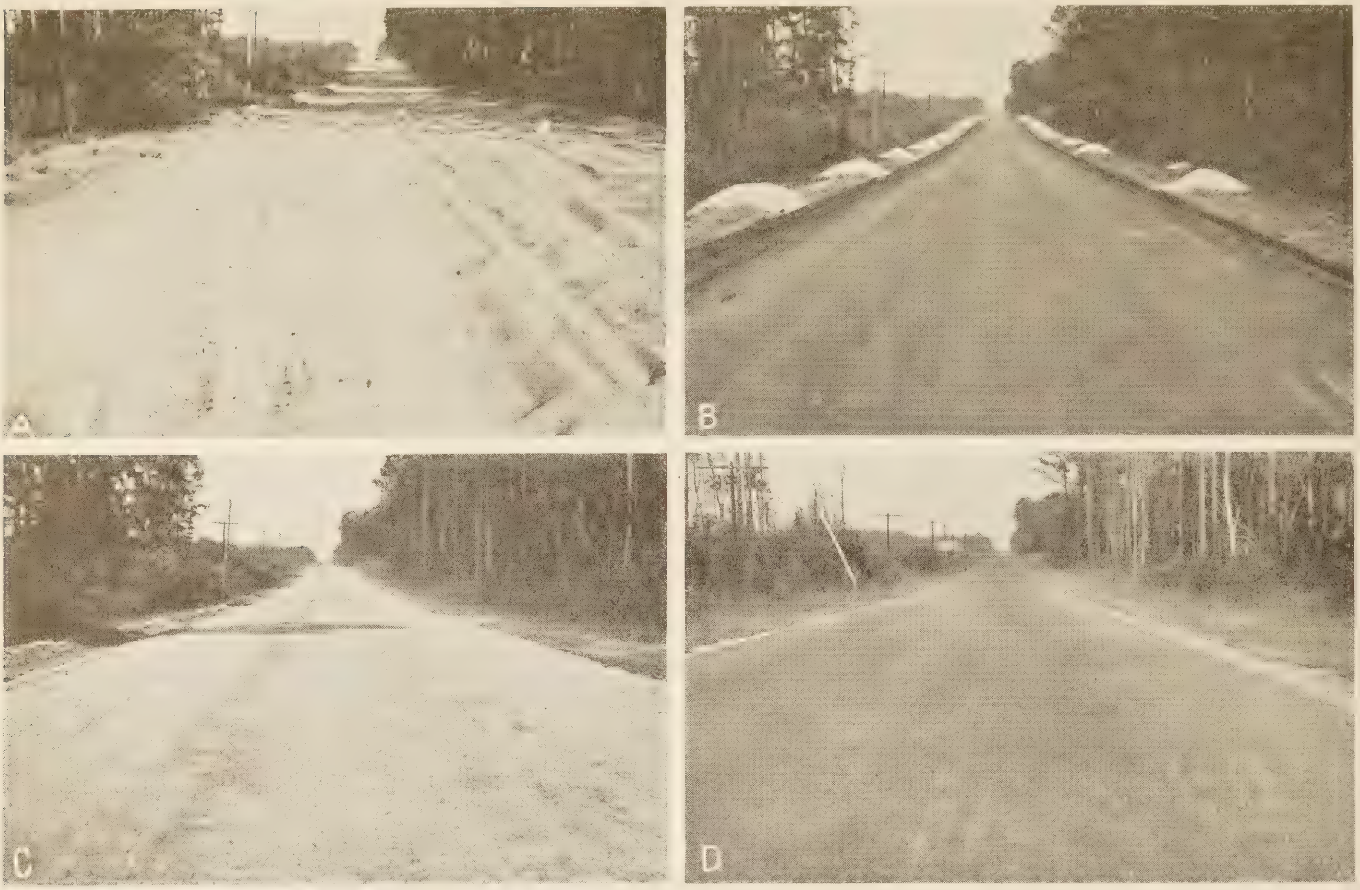


Figure 5.—Experiment 7–B at Station 898 During and After Construction. A, Loosened Roadbed Prior to Applying Bitumen; B, Mixed Base Completed and Ready for Surface Treatment; C, Surface Treatment Completed, Road Ready for Traffic; D, Appearance of Road 4 Years After Construction and 6 Months After the Only Surface Treatment It Has Received.

Figure 6.—Appearance of Experiment 7–B at Station 898 Seven Years After Construction and 3 Years After the Only Surface Treatment It Has Received.

warmed to obtain uniform distribution. Mixing was carried out promptly to insure thorough and uniform coating of all particles before the volatile constituents of the bitumen should be dissipated. However, no difficulty was experienced in this respect and ample time was available for mixing and spreading the mixture, even when rainy weather temporarily interrupted the mixing operation or made additional manipulation necessary for drying the mixture.

The methods of construction just described are in common usage today and need no further explanation. Figures 5 and 6, views taken at station 898 on experiment 7–B, illustrate the appearance of the road during its transition from an unimproved to an improved structure.

SURFACE ROUGHNESS CAUSED MAINLY BY UNSTABLE SUBGRADE

The costs of constructing the various experimental sections are given in table 6 together with the annual costs, which include re-treatments and maintenance of the bituminous mats but do not include any other maintenance costs.

The early behavior of the different experimental sections varied considerably as might be expected, but without exception, was a decided improvement over that of the untreated surface at its best. The dust nuisance was eliminated; traffic capacity was increased; riding qualities were greatly improved; there had been provided an all-weather surface which, with reasonable care, was satisfactorily maintained; and if necessary the road could have been economically bettered to meet increased demands, utilizing to a great extent the original investment.

Almost simultaneously with the completion of the sections, a number of failures demonstrated various weaknesses. The most outstanding unsatisfactory feature was surface roughness which, compared with that of the old road, was negligible but compared with that of the new surfaces in general, was very pronounced. While much of the roughness resulted from subgrade movement, other causes brought about the

TABLE 6.—*Cost of construction, re-treatments, and maintenance of the various experimental sections*

Section		Construction					Annual cost per square yard of re-treatments and maintenance of the bituminous surfaces only															
		Mixed base		Surface treatment			1927–28		1928–29		1929–30		1930–31		1931–32		1932–33		1933–34			
No.	Stations	Thickness	Bituminous material	Bituminous material	Cover	Cost per square yard	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Total	Average annual cost
		Inches				*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
1-A	0-100	2	Cut-back asphalt	Hot asphalt	1¼-¼-inch stone	33.76		5.12	6.24	2.08	11.36	2.49	9.85	2.09		1.30	14.11	3.54	11.12	4.50	73.80	10.36
1-B	100-150	2	do	do	do	[1] 32.22		4.82		3.23	[2] 7.09	1.60	9.85	3.96		1.69	14.11	2.80	[2] 7.11	5.13	61.39	8.69
2-A	150-180	2	do	Cut-back asphalt	do	35.11	4.25	1.41		1.88		1.21		2.09		.61	14.11	1.99		.91	28.46	4.09
2-B	180-205	2	do	do	Pea gravel	30.17	5.31	6.35	6.82	1.83	[2] 7.00	1.13	8.65	1.00					15.31	21.17	74.57	10.65
2-C	205-221	2	do	do	Sand	34.52	4.53	6.86	26.66	2.73	16.91	3.05		.77	9.95	.89		1.04	14.73	16.88	105.00	15.00
2-D	221-235	2	do	do	do	37.06	4.35	5.08	[2] 15.24	2.06	12.74	2.51		1.04	9.95	2.49			14.73	4.29	74.48	10.64
2-E	235-265	2	do	do	Pea gravel	35.51	6.69	1.01		2.03	[2] 2.81	1.69		1.96	9.95	1.86		.06		.74	28.80	4.11
2-F	265-295	2	do	do	1¼-¼-inch stone	37.06	13.29	2.28		.93		1.36	9.28	2.50							29.64	4.23
2-G	295-313	2	do	do	do	45.46	31.85	3.16		2.67		2.01	9.28	1.98							50.95	7.28
2-H	313-333	2	do	do	Pea gravel	44.61	23.40	7.14	9.20	5.77	11.99	2.53		.46		.17	11.68	.18		.38	72.90	10.41
2-I	333-350	2	do	do	Sand	35.71	16.00	7.26	8.56	4.56	11.95	1.93		.51		.40	11.68	.35		.45	63.65	9.09
3	350-400	2	Slow-curing oil A	Enriched with slow-curing oil A.	Treated soil	23.04		7.03	13.32	3.18		3.89		1.24		1.61	5.08	.09		.46	35.90	5.19
4-A	400-426	3	Slow-curing oil B	None	None	28.42		6.07	[2] 6.57	4.43		3.57		1.92		1.79	13.42	.28		.84	38.89	5.62
4-B	426-452	3	Slow-curing oil C	None	None	24.39		7.33		6.16	9.33	6.38		1.52		1.46	13.42	.84		.90	47.34	6.84
4-C	452-477	3	Slow-curing oil D	None	None	28.50		7.01	1.22	4.33	10.37	8.62		1.93		.80	13.42	.38		.94	49.02	7.08
5-A	477-503	2	Cut-back asphalt	Enriched with slow-curing oil E.	Treated soil	33.70		3.72	30.45	3.49	16.13	2.71		1.19		.70		.64		.20	59.23	8.67
5-B	503-530	2	do	Enriched with cut-back asphalt.	do	30.95		3.24		2.41		3.36		1.17		1.45	11.39	1.54			24.56	3.58
5-C	530-556	3	do	do	do	41.33		1.34		1.26		1.66		1.41		.71	10.59	.72			17.69	2.57
5-D	556-582	3	do	Enriched with slow-curing oil E.	do	41.05		2.11		3.61	11.90	1.61		.66			10.59	.32			30.80	4.51
6-A	582-610	2	18-25 viscosity tar	Enriched with 18-25 viscosity tar.	do	49.36		2.38		3.38		3.07	10.10	1.71				.12		.42	21.18	3.10
6-B	610-636	3	do	do	do	63.94		4.50		2.82		2.75	10.23	3.33		.90		.40		3.58	28.51	4.18
6-C	636-688	2	do	25-35 viscosity tar, cold	1¼-¼-inch stone	63.29		2.31		2.97		1.01	11.22	1.14		.23		.06			18.94	2.78
6-D	688-742	2	do	Hot tar	do	62.31		2.31		2.42		.75	10.89	1.14				.06			17.57	2.59
6-E	742-794	2	do	do	do	59.89		1.70		2.91		.93	10.10	2.73				.71		.18	19.26	2.84
7-A	794-846	2	Cut-back asphalt	Hot asphalt	do	46.17		3.54		2.00		1.39	[2] .38	2.61	9.87	1.37		.09		.22	21.47	3.21
7-B	846-950	2	do	do	do	48.64		2.95		1.74	[2] .97	.87	9.81	1.30	[2] .05			.01		.02	17.72	2.63
7-C	950-1000	2	do	Cut-back asphalt	do	45.26		2.14		4.01	[2] 4.65	1.72	9.81	1.98				.06		.28	24.65	3.68
8	1000-1087		Untreated sand-clay soil.	Hot asphalt	do	24.99	3.69	3.32		1.94	[2] 8.76	1.36	[2] 2.93	1.56				.07			23.63	3.54

[1] Includes re-treating last 500 feet of the section shortly after construction.
[2] Treatment applied to part of section only but cost is prorated over entire section.

Figure 7.—A, Failure of Surface Treatment on Experiment 5–D, Which Was Constructed by Enriching the Top Portion of the Mixed Mat with Slow-Curing Oil. B, Appearance of Experiment 5–A Shortly After Construction. Its Surface, Which Was Enriched With Slow-Curing Oil, Scaled and Pot-Holed. The Base, Which Was Poorly Drained, Became Very Unstable.

same result. One of these was surface enrichment of the mixed mats designed to carry traffic without additional surface treatment or the use of coarse cover material. The upper portion of the mat peeled off to about the depth of enrichment, resulting in a rough, pot-holed surface. This condition, illustrated in figure 7, was eventually eliminated by a re-treatment in which a stone cover was used.

Another cause of roughness was the instability of the mixed base itself due to an improper combination of bituminous material and sand-clay. In some cases the amount of bituminous material used was apparently incorrect for an entire section; in others it was apparently correct for the major portion of the section but unsatisfactory for other portions because of variations in the sand-clay within the section. Tables 4, 5, and 7 indicate the wide variations in grading, not only among the sections but within a given section, which made it practically impossible to design a uniformly satisfactory mixture and would have made it impossible to have applied an empirical proportioning formula had such a formula been available at the time.

The bitumen content of the mixed bases, as determined by extraction tests, varied considerably. While the resulting mixtures are probably lean and might be unable to withstand traffic without a protective covering, increased stability has probably been obtained with the result that there has been less movement of the mat than would have occurred had the mixture been richer.

The most important factor contributing to roughness during most of the life of the road has been the subgrade, which is extremely variable in composition and, in some locations, is very poorly drained. Settlement occurred in some areas that had appeared stable prior to constructing the bituminous mats. Investigation disclosed that the subgrade in such areas was extremely wet and plastic while material less than a foot outside of the bituminous mat was firm and relatively dry. The mat apparently prevented surface evaporation and permitted the subgrade to acquire and retain sufficient moisture to destroy its stability. Obviously, the composition could not be changed after construction but considerable effort has been expended to provide artificial drainage. The groundwater level in many cases is so high that the maximum benefit derived by the construction of side ditches is to provide a relatively shallow depth of drained base which, because of its composition, is variable in load supporting capacity.

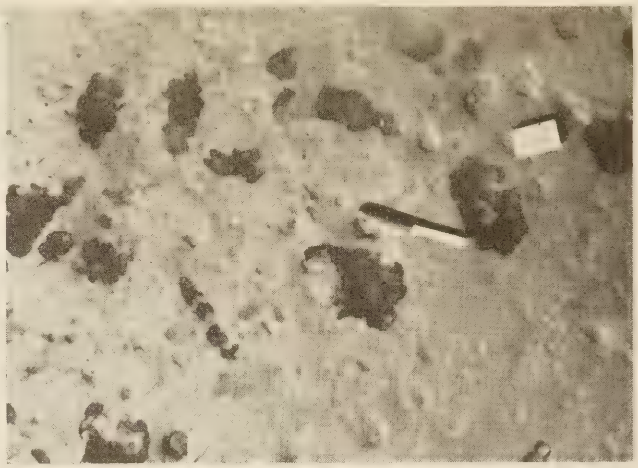


Figure 8.—Incipient Pot-Holing, Which Was Characteristic of Portions of Experiment 4.

Two other factors contributing to surface roughness were ordinary pot-holing and edge failure. The former, illustrated in figure 8, appeared in the sections designed for machine maintenance and was caused primarily by a lack of bituminous material. The latter type of failure appeared in varying degrees in most of the sections but was more pronounced on those in which fine grained or no cover materials were used. On such sections, steel-tired vehicles damaged the edges as illustrated in figure 9.

CONSTRUCTION AND RE-TREATMENT OF EACH EXPERIMENTAL SECTION DESCRIBED IN DETAIL

Another unsatisfactory and unsightly condition developed—bleeding or flushing of bitumen to the surface. This condition, which highway engineers are still striving to eliminate, appeared wherever the base became softened by an excess of bitumen, moisture, or clay, or a combination of these in an amount sufficient to permit the cover material to become embedded in the mixed bituminous base or in the sand-clay base. Where the bases were not thus softened and the cover material remained on the surface, bleeding did not occur.

Samples were taken 7 years after construction from areas representing various typical conditions. Analyses of subgrades and bituminous mats were made and are given in table 7 together with a description of the area represented at the time samples were taken.

Experiment 1, extending from station 0 to station 150, had a 2-inch mixed base of sand-clay and cut-back asphalt. It was primed with cut-back, sealed with hot asphalt, and covered with crushed stone.

This experimental section, which began at the northwest city limits of Conway and extended 3 miles northwest, was divided into sections A and B, which differed only in the cut-back asphalt used in the mixed base and prime application. On section A this bituminous material was a cut-back of 150 to 180 penetration asphalt and on section B a cut-back of 85 to 100 penetration asphalt was used.

As shown in table 4, samples of the sand-clay taken from various places on the experimental section showed considerable variation in composition. Many areas were low and poorly drained, as artificial drainage was not provided until later.

This was the first experimental section built and almost immediately after construction it was apparent that the bitumen content of the base was too low. Although surface-treated with hot asphalt and stone, the edges soon crumbled and broke badly, necessitating an additional treatment for a width of a few feet at the edges. Early movement of the mat resulted in a rough riding surface which has been, in general, characteristic of a considerable portion of this experimental section. To eliminate some of this roughness a 500-foot length at the west end of section B was given a re-treatment in July 1927. This treatment added to the surface smoothness considerably but shoving later developed at the extreme west end of the section due to unsatisfactory drainage conditions.

Since construction section A has received four complete and two partial re-treatments while section B was given two complete and two partial re-treatments exclusive of the 500-foot length re-treated as a part of its original construction. These re-treatments were applied primarily to seal cracks which had developed and to eliminate surface roughness.

During this same period considerable effort was made to provide drainage by the construction and maintenance of deep side ditches and by the installation of French drains. As a routine maintenance measure, badly shoved areas were repaired by removing the unstable material below the base, placing stone-filled trench drains, refilling with satisfactory base material such as cinders or coarse crushed stone, and then replacing the bituminous mixtures or using bituminous-coated stone. On many areas the result of such repair was a smooth surface which continued in good condition, but on other portions of the section identical repairs had to be made at intervals, especially on the low side of curved areas.

Prior to applying the re-treatment in May 1933, considerable effort had been made to remove all rough areas caused by subgrade movement. This treatment, consisting of 0.65 gallon of 85 to 100 cut-back and 60 pounds of ¾- to ¼-inch stone per square yard, was the heaviest treatment applied and contained sufficient materials to produce a mat of appreciable thickness. The section at first appeared to have been greatly improved by this treatment, but by the following spring those areas on which the subgrade had previously been troublesome again developed excessive roughness, shoved considerably, and required much additional maintenance. Figure 10 illustrates an excellent as well as an unsatisfactory area typical of the section in February 1934.

The slight variation in type of bituminous materials used in the mixed bases of sections A and B was at no time reflected in their behavior. There was no greater variation in behavior between the sections than within portions of each section. Construction and average annual maintenance costs of this experiment are shown in table 8.

FIGURE 9.—STEEL-TIRED VEHICLES WERE ESPECIALLY DESTRUCTIVE TO THE EDGES OF THE SECTIONS OF EXPERIMENTS 2 AND 5, WHICH HAD NOT RECEIVED ADEQUATE SURFACE TREATMENT. ARROWS INDICATE ORIGINAL EDGE OF THE MAT.

PERFORMANCE OF EXPERIMENT 2 AFFECTED BY SUBGRADE AND DRAINAGE CONDITIONS

Experiment 2, extending from station 150 to station 350, had a 2-inch mixed base of sand-clay and cut-back asphalt which was sealed with cut-back asphalt and covered with crushed stone, gravel, or sand.

Experiment 2 was divided into three groups of three sections each. They were constructed indentically except that the cut-back asphalt differed in each group and also that in each group one section was covered with 1¼- to ¼-inch crushed stone; one was covered with pea gravel; and one was covered with sand. The cut-backs used were made of 85 to 100, 100 to 120, and 150 to 180 penetration asphalts.

As in the case of experiment 1, subgrade and drainage conditions in this experimental section were exceedingly variable. Each section had sandy areas, areas high in clay content, poorly drained areas, and areas fairly well drained. Sections A, E, F, and G, however, had somewhat better natural drainage than the other five sections of this experiment.

Rainy weather encountered during base construction necessitated a considerable amount of manipulation for drying as well as for mixing the base materials. The seal treatment was applied directly to the mixed bases after they had been subjected to traffic for periods ranging from 4 to 30 days. On each section the bituminous

TABLE 7.—*Analyses of bituminous mats and subgrades from areas typical of the experimental road in 1934 (7 years after construction)*

BITUMINOUS MIXTURES

Experiment no.	1-A	1-B	3			4-B	4-C		5-C	6-A	6-B	7-C	8	
Sampled at station no.	63	145	353	363	398	440	453	457	543	585	630	981	1054	
Condition of wearing surface at location sampled	Mat almost gone; surrounding area has been heavily patched; slight fill through swampy section [1]	Very good and has always been so; free from cracking and raveling; drainage good [2]	Good, smooth, uncracked, on slight fill; drainage good [3]	Mat almost gone; bad area on curve; drainage poor; slight cut [4]	Smooth, cracked but not raveling; drainage fair	Rough, unstable in warm weather; old mat fairly firm; drainage poor	Fairly stable; some pitting due to clay balls; drainage fair	Very good; some hair-cracking but no raveling; drainage fair	Very good; mat stable; drainage good	Rough but stable; lies in a swampy section; natural drainage fair	Rough but stable; drainage is good	Very good; no cracking or raveling; drainage good	Very good; stable and free from cracking or raveling; drainage good	
													Left side	Right side
Laboratory no.			39359	39358	39357	39356	39355	39354	39362	39361	39360			
Original or remixed base or surface			Remixed 1933.	Remixed 1933.	Remixed 1933.	Remixed 1933.	Remixed 1933.	Remixed 1933.	Original.	Original.	Original.			
Bituminous material used			Slow-curing oil.	Slow-curing oil.	Slow-curing oil.	Slow-curing oil.	Slow-curing oil.	Slow-curing oil.	Cutback	Tar	Tar			
Material represented—base or surface			Both	Both	Both	Both	Both	Both	Mixed base.	Mixed base.	Mixed base.			
Depth of mixed base or surface, inches			2¾-3	1 (approx.).	2⅜-2¾	4	3	4-4½	2¾-3¼	3	4-4¼			
Hubbard-Field stability at 77° F., pounds:														
Top inch [5]			1,620	1,730	2,910	[6] 270	940	1,160	5,400	5,575	5,710			
Second inch [5]			1,550		830	[6] 40	700	990	2,940	3,640	5,460			
Third inch [5]						[7] 3,050		940			4,525			
Fourth inch [5]						[7] 2,000		1,090						
Composite of above, remolded [8]			770	1,790	970	[6] 0–[7] 1,570	630	450	1,900	3,120	2,330			
Extraction and grading:						(6) (7)								
Bitumen ... percent			7.1	6.8	9.2	9.2 9.3	7.0	10.2	[9] 7.7	7.0	8.7			
Passing ¼ inch, retained No. 10 ... percent			.1	.2		.1 .2	.1	.1	.5	.8	.1			
Passing No. 10, retained No. 20 ... percent			.8	.4	.6	.2 .5	.4	.3	.5	.4	.4			
Passing No 20, retained No. 30 ... percent			3.1	1.5	1.2	.2 .8	.7	.9	.4	.4	1.4			
Passing No. 30, retained No. 40 ... percent			5.4	5.6	2.1	.9 1.9	1.8	1.5	1.2	.8	3.6			
Passing No. 40, retained No. 50 ... percent			5.4	5.9	2.9	1.4 3.2	2.7	2.1	1.7	1.7	4.6			
Passing No. 50, retained No. 80 ... percent			15.5	15.0	25.5	15.5 23.2	24.2	20.2	11.7	23.9	26.2			
Passing No. 80, retained No. 100 ... percent			16.5	16.8	21.6	33.5 20.6	25.7	23.6	22.9	23.1	23.2			
Passing No. 100, retained No. 200 ... percent			35.9	34.7	24.0	32.0 26.2	27.3	30.4	31.0	28.0	22.0			
Passing No. 200 ... do			10.2	13.1	12.9	7.0 14.1	10.1	10.7	22.4	13.9	9.8			

SUBGRADES

Laboratory no.	8157	8158	8159	8154	8155	8156	8153	8152	8151	[10] 6081	[10] 6082	8149	8148	6080	6067	8169	8147	8143	8144	8145	8146
Portion represented by sample inches	Top 6	6 to 12	12 to 18	Top 5	5 to 10	10 to 15	-	-	-	Top 5	Next 5	-	-	-	-	-	-	Top 6	6 to 10	10 to 14	-
Mechanical analysis:																					
Particles larger than 2.0 mm percent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	([11])	0	0	0	0	0
Coarse sand, 2.0–0.25 mm do	8	47	25	24	22	15	31	15	6	4	6	3	6	1	6	([11])	3	43	38	42	45
Fine sand, 0.25–.05 mm do	26	21	33	44	42	27	52	58	60	48	71	65	77	36	72	([11])	69	15	20	23	34
Silt, 0.05–.005 mm do	26	11	17	19	18	15	3	11	10	10	9	7	5	37	5	([11])	13	18	20	15	8
Clay, smaller than 0.005 mm do	40	21	25	13	18	43	14	16	24	38	14	25	12	26	17	([11])	15	24	22	20	13
Colloids, smaller than 0.001 mm percent	32	17	21	10	12	36	12	14	18	32	10	18	10	11	11	([11])	9	14	10	10	9
Characteristics of material passing No. 40 sieve:																					
Percent passing	97	62	88	93	95	96	87	93	98	-	-	99	99	-	-	-	99	74	83	80	81
Liquid limit	41	33	32	14	15	47	19	20	27	42	15	27	18	28	26	16	17	33	35	22	15
Plasticity index	25	19	18	0	4	29	5	5	13	24	0	13	0	13	9	0	0	14	14	8	0
Shrinkage limit	13	14	15	-	14	14	-	18	16	19	-	15	-	18	21	-	-	23	25	17	-
Shrinkage ratio	1.9	1.9	1.9	-	1.9	1.8	-	1.7	1.8	1.7	-	1.8	-	1.8	1.7	-	-	1.6	1.5	1.8	-
Centrifuge moisture equivalent	26	22	21	11	14	26	10	14	13	24	8	14	6	21	14	5	9	26	28	17	7
Field moisture equivalent	24	19	21	14	13	27	18	19	19	26	17	19	21	19	20	20	19	25	27	17	15
Soil group	A-6	A-2 plastic	A-2 plastic	A-3	A-2 feebly plastic	A-6	A-2 plastic	A-2 plastic	A-2 plastic	A-6	A-3	A-2 plastic	A-3	A-4	A-2 plastic	A-3	A-3	A-2 plastic	A-2 plastic	A-2 plastic	A-3

[1] Condition shown in figure 10-B.
[2] Condition shown by figure 10-A.
[3] Condition shown by figures 14 and 15.
[4] Condition shown by figure 13.
[5] Field specimens tested as received.
[6] Data for new sand-oil mat built on old surface in 1933.
[7] Data for old surface prior to 1933.
[8] Under direct compression of 3,000 pounds per square inch.
[9] Mix heated in oven for 5 hours at 163° C. (325° F.) lost 1.42 percent by weight, equivalent to 18.44 percent of its bitumen content.
[10] Samples taken at station 436.
[11] Insufficient material.

FIGURE 10.—TYPICAL VIEWS OF SATISFACTORY AND UNSATISFACTORY PORTIONS OF EXPERIMENT 1, SEVEN YEARS AFTER CONSTRUCTION. ANALYSES OF SUBGRADES FROM THESE AREAS ARE GIVEN IN TABLE 7. A, AT STATION 145 OF EXPERIMENT 1–B. B, AT STATION 63 OF EXPERIMENT 1–A; FAILURE CAUSED BY PLASTIC SUBGRADE.

TABLE 8.—*Construction and average annual maintenance costs per square yard for experiment 1*

Section	Construction costs				Average annual maintenance cost
	Bituminous material	Stone cover	Labor and equipment	Total	
	Cents	*Cents*	*Cents*	*Cents*	*Cents*
A	17.16	7.64	8.96	33.76	10.36
B	16.96	7.65	7.61	32.22	8.69

material used in the seal was the same as that used in the mixed base. Crushed granite, 1¼- to ¼-inch, was the cover material for sections A, F, and G; pea gravel was used on sections B, E, and H; and a local sand was used on sections C, D, and I.

One month after construction, section H had broken up to such an extent that it was necessary to remix it with additional bitumen and reseal it. Other sections of experiment 2 exhibited various defects which were not of sufficient proportion to warrant reconstruction.

In December 1927 experiment 2 was re-treated with the same types of bituminous and cover materials that were used in construction except that sand instead of stone cover was used on section A. In addition, sections G, H, and I were remixed with additional bituminous material prior to applying the re-treatment. Since 1927 the stone-covered sections have received only one re-treatment: Section A in 1933; and sections F and G in 1931.

Of the gravel-covered sections (B, E, and H) section E continued the most satisfactory, the re-treatments having been limited to a treatment of the last 950 feet of the section in 1930 and to the entire section in 1932. Section H was re-treated in 1928, 1930, and 1933 and in each treatment stone cover was used instead of pea gravel. Section B, still maintained as a pea-gravel covered section, was re-treated in its entirety in 1928, 1931, and 1934 and approximately half its area was remixed and re-treated in 1929.

The sand-covered sections C, D, and I soon became rough, pot-holed, and unstable, and their edges raveled under steel-tired vehicles. Sand was used as the cover material in the re-treatment of the entire experiment in 1927 and to cover section C and part of section D, after they were remixed in 1928. The recurrence of surface failures, however, led to the substitution of stone as the cover material in the subsequent re-treatments applied to sections C and D in 1929, 1932, and 1934 and to section I in 1928, 1930, and 1933.

Figures 9–B and 11–A illustrate the unsatisfactory surface conditions that existed on these sections during the period when the wearing surfaces were composed of sand and cold-application bitumen. They also illustrate the unsatisfactory drainage conditions existing at the time the sections were built and during their early life.

With the substitution of stone as the cover material and with the construction of side ditches and lateral drains, the unsatisfactory behavior was largely eliminated and the service behavior of the sections became comparable to that of the other sections of this experiment.

Construction and maintenance costs of this experiment per square yard are shown in table 9.

TABLE 9.—*Construction and average annual maintenance costs per square yard for experiment 2*

Section	Cover	Construction costs				Average annual maintenance costs
		Bituminous material	Cover material	Labor, supplies and equipment	Total	
		Cents	*Cents*	*Cents*	*Cents*	*Cents*
A	Stone	23.18	6.72	5.21	35.11	4.09
B	Gravel	21.83	2.59	5.75	30.17	10.65
C	Sand	24.82	.20	9.50	34.52	15.00
D	do	25.22	.22	11.62	37.06	10.64
E	Gravel	27.26	2.59	5.66	35.51	4.11
F	Stone	23.57	6.72	6.77	37.06	4.23
G	do	26.19	7.45	11.82	45.46	7.28
H	Gravel	30.17	[1] 4.55	9.89	44.61	10.41
I	Sand	23.28	.18	12.25	35.71	9.09

[1] Includes 2 applications of gravel cover, the first of which was incorporated into the mixture when the section was reconstructed 1 month after original construction.

SURFACE CRACKS DID NOT IMPAIR EXPERIMENT 3

Experiment 3, extending from station 350 to station 400, had a 2-inch mixed base of sand-clay and slow-curing oil A. Its surface was enriched with oil A and covered with bitumen-coated sand-clay.

This experiment, approximately 1 mile in length, was one of the sections in which a slow-curing oil was used and was designed for machine maintenance.

On this experiment the subgrade and drainage were somewhat better than on the two preceding experimental sections, except for a short portion, in the vicinity of station 365, which lay in a swampy area.

During construction a severe storm interrupted the mixing operation and the heavy rainfall washed a considerable but undetermined amount of oil into the side ditches. When mixing had been completed the surface did not bond and the quantity of oil, with which it was planned to enrich the top portion of the mat by penetration, was increased to 0.65 gallon per square yard. This application was covered with oil-treated sand-clay. Except for occasional light blading to retain surface smoothness, this completed the construction of the section.

In general, the behavior of experiment 3 during the period covered by this report has been good. It has been scarified and remixed three times since construction. In two of these remixing operations, those of 1928 and 1933, oil was added, but the remixing in 1929 was done primarily to eliminate instability which had developed in the bituminous mat due to excess moisture.

The section was similar to a sheet asphalt pavement in texture but its color was brown and it had acquired a somewhat glazed surface under traffic. The major portion of this experiment remained fairly smooth but three relatively small areas continued rough and spongy as if excessively rich in bitumen. However, an unstable base, poor drainage, and the presence of water was the cause of instability rather than excessive bitumen. Practically all of the experimental section was covered with fine hair cracks throughout most of its life. Except in the areas more greatly affected by moisture, this cracking apparently had not seriously affected the behavior of the section. Figure 11–B illustrates the most advanced stage of cracking which, although unsightly, did not progress to the stage of disintegration.

Although designed for machine maintenance, the surface eventually crusted so that dragging for surface smoothness was not practical and depressions were usually filled with premixed material. High spots were easily cut with a blade but the material so removed was whipped from the surface by traffic rather than compacted into the low spots.

The cost per square yard of constructing this experiment was as follows:

	Cents
Bituminous material	17.78
Labor, supplies, and equipment	5.26
Total	23.04

The average annual maintenance cost was 5.19 cents per square yard.

In the period subsequent to that covered by this report, an unsatisfactory condition developed that seriously affected the service record of experiment 3. The surface glaze, previously referred to, became very pronounced in the intervals during which the surface was not disturbed by machining or remixing. The glazed surface became very slippery in wet weather and so dangerous to traffic that the highway department, in 1935, applied a surface treatment of cut-back asphalt and stone.

ORIGINAL CONSTRUCTION ON EXPERIMENT 4 BECAME HARD AND BRITTLE, REQUIRING RE-TREATMENT

Experiment 4, extending from station 400 to station 477, had a 3-inch mixed mat of sand-clay and slow-curing oils, B, C, and D.

Experiment 4 also was designed for machine maintenance and its construction was similar to that of experiment 3 except that all of the bitumen applied was mixed with sand-clay to form the mat. The experiment was divided into three sections which differed only in the kind of oil used.

Figure 11.—Inadequate Drainage Contributed to Base Failure on These Experimental Sections. A, Both Base and Surface Failed on Experiment 2, Sections C and D. Sand Was Used With a Cold-Application Material for Surface Treatment, Resulting in a Rich, Plastic Mixture. B, Badly Cracked Area on Experiment 3, Caused by a Plastic Subgrade.

Subgrade and drainage conditions were quite variable in each of the sections but were somewhat better in section C than in sections A and B. Portions of sections A and B lay in low, swampy areas where the ground water level was very close to the elevation of the road surface. The character of the sand-clay was exceedingly variable. At some time prior to construction of the experimental sections, clay had been used where needed to fill holes. Apparently, no attempt had been made to mix the clay with the material already in the road, consequently the base and the sand-clay in the mixed mat ranged from very sandy mixtures to mixtures high in clay content. This was especially true of the west portion of section B and the east portion of section C.

When the sections had been laid down and compacted under traffic, they were similar in appearance to experiment 3 except that the glaze was more pronounced and, in general, they appeared harder and less malleable. Material loosened by dragging or light blading did not readily rebond but was dissipated by traffic.

The first remixing was done to section A in 1928. The east 600 feet were not remixed, as that portion of the section was in excellent condition. The next 1,000-foot portion, which had become rutted through the swampy area and also was badly pot-holed elsewhere, was scarified and remixed with approximately 1 gallon of oil A per square yard. The remaining 1,000-foot portion on the west end of the section appeared hard, firm, and only slightly pot-holed but had a decided tendency to dust under traffic. It was decided to experiment by lightly scarifying the top portion of this area, and adding about one-half gallon of oil A per square yard, which, with a small amount of sand-clay brought in from the sides, formed a thin new wearing surface for the old mat. The plan was successful as the new material bonded readily to the old mat and dusting under traffic stopped.

Sections B and C were first remixed in 1930 with approximately 0.8 gallon of oils C and D per square yard, respectively, the same oils as were used in the original construction.

All three sections were again treated in 1933. It was attempted in this treatment to raise the grade through the swamp on section A and to elevate the outside edges of two sharp curves on sections B and C. On section A the additional sand and oil added to raise the grade were mixed with the old mat which had been scarified. The curves on sections B and C were elevated by building a new mat on top of the old one. The remaining portions of this experiment were remixed with additional oil.

The remixing operations revealed considerable differences in the character of the mixture on experiment 3 as compared with experiment 4. The mat on experiment 4 broke up readily and required only a small amount of harrowing and blading to reduce it to a uniformly fine mass which did not appear at all "alive". The mat of experiment 3, on the other hand, was malleable and in spite of considerable harrowing and blading did not break down into a uniformly divided condition. Under the traffic that passed while the work was being done the pulverized material on experiment 4 compacted but did not rebond, while that on experiment 3 not only compacted but rebonded to such an extent that additional manipulation was necessary before the oil was added. Upon adding the oil and remixing, however, the scarified portions of experiment 4, in general, compacted and bonded very much better than those areas on which a new mix was built upon the old mat.

On those portions of the experimental section previously referred to as containing considerable clay, it was noted that within a few days after the mix had been relaid small areas in the center of the road were cracked and raveling. These spots and the surrounding areas were immediately remixed and relaid, and within 3 hours under traffic the same undesirable features reappeared in the same locations. Upon removing the mix a 2-inch layer of wet, sticky clay was found between the bituminous mat and the sandy base. This layer of clay was removed from portions of these areas and the bituminous mix replaced. No cracking or raveling reappeared and the small areas thus repaired remained in excellent condition. The particular locations of these areas of failure, directly under the area of concentrated traffic, suggest the possibility of movement or flow of clay under the vibrating action of traffic. It appeared most practical not to attempt to remove all of the heavy clay deposits from the base because of the irregularity of their location but to make repairs as a maintenance measure when and where necessary.

The construction and average annual maintenance costs for each of the sections of this experiment are given in table 10.

Table 10.—*Construction and average annual maintenance costs per square yard for experiment 4*

Section	Construction costs: Bituminous material	Construction costs: Labor, supplies, and equipment	Construction costs: Total	Average annual maintenance costs
	Cents	*Cents*	*Cents*	*Cents*
A	23.78	4.64	28.42	5.62
B	19.75	4.64	24.39	6.84
C	23.86	4.64	28.50	7.08

A slippery surface developed on experiment 4 similar to that which developed on experiment 3, and at the same time. The same remedial measures were applied to both experimental sections at the same time.

STEEL-TIRED VEHICLES WERE DESTRUCTIVE TO EDGES OF EXPERIMENT 5

Experiment 5, extending from station 477 to station 582, had 2- and 3-inch mixed bases of sand-clay and cut-back asphalt. The surface was enriched with slow-curing oil E and cutbacks, and was covered with bituminous-treated soil.

This experiment comprised four sections—A, B, C, and D. The mixed bases of sections A and B were 2 inches thick and those of sections C and D were 3 inches thick.

The bases were mixed with 85 to 100 penetration cut-back asphalt, spread and compacted by traffic. A small amount of the mixed base was windrowed to the sides to be respread after the surface enrichment application had been made. The bituminous material used for this purpose on sections A and D was the slow-curing oil E, similar to that used in experiment 4, and on sections B and C it was a 150 to 180 penetration cut-back asphalt. Approximately 0.4 gallon per square yard was used on each of the sections.

The subgrade and drainage of this experiment, while varying somewhat, were better than on the preceding experimental sections. With the exception of part of section A, good natural drainage and fairly stable subgrade were characteristic of this experimental section. The exception was approximately the center third of section A, which lay in low swampy area very difficult to drain. Side ditches were of no great benefit as they quickly filled with sand and silt and permitted surface water to reach almost to the bituminous mat. This condition is illustrated in figure 7–B. About 1930, however, the entire swampy area was drained and the ground-water level lowered so that recently there have been no failures directly attributable to unstable subgrade.

The sections immediately after construction resembled a sheet asphalt pavement, with sections B and C appearing more substantial than sections A and D. The surfaces of sections A and D scaled and pot holed badly, section D more so than A. There appeared to be little bond between the enriched surface portion and the relatively lean base, as the surface shoved, peeled, and pot-holed to the approximate depth of enrichment. This type of failure is illustrated in figure 7–A.

Sections B and C were similar in appearance and behavior. While pot-holing and surface roughness were far less pronounced than on sections A and D, the edges of the mats did suffer severely under steel-tired vehicles that cut through the mix as illustrated in figure 9–A. Considerable early maintenance, consisting of placing new mixture along the edges, was required to maintain the original road width.

Section A developed roughness, pot-holed, and became unstable due to what was thought to be excessive richness. By December 1928 it was in such unsatisfactory condition that reconstruction was deemed advisable. When the section had been scarified and pulverized it was evident that the apparent richness was caused primarily by moisture and not by excess bitumen. One and one-quarter gallons per square yard of 85 to 100 penetration cut-back asphalt were added and the section was remixed. After compaction under traffic the surface was sealed with 0.38 gallon per square yard of the same type of cut back, covered with 50 pounds per square yard of 1¼- to ¼-inch stone, and then rolled. Its condition prior to scarifying and re-treating is illustrated in figure 7–B.

By the fall of 1929 the section had again become unstable and extremely rough, and again it was scarified and remixed, but without adding bitumen. It was then resealed with 0.38 gallon of 85 to 100 penetration cut-back asphalt and 50 pounds of 1¼- to ¼-inch stone per square yard and rolled. About this time a drainage ditch, constructed through the swamp, removed the water from the surrounding area and, with the side ditches then capable of handling surface water, the subgrade became stable and has so remained. Except for a rather lean surface appearance, the section in July 1934 was in better condition than at any previous time.

Section D, which was identical with section A except that its bituminous base was 3 inches thick, was re-treated in the fall of 1929 to eliminate excessive roughness and to preserve the mixed base. The treatment consisted of applying 0.39 gallon of 85 to 100 cut-back asphalt and a cover of 40 pounds of ¾- to ¼-inch stone per square yard. This treatment greatly benefited the section by eliminating most of the roughness and scaling of the mat.

Sections B and C continued in fair condition except for the roughness and edge failure already noted. Maintenance of these two sections consisted mainly of building up the edges and removing depressions, using for this purpose a mixture of sand-clay and cut-back asphalt. In May 1933 they were in fair condition for the surface treatment that was applied to them and to section D. The treatment consisted of 0.46 gallon of 85 to 100 penetration cut-back asphalt and 40 pounds of ¾- to ¼-inch stone per square yard.

The construction and average annual maintenance costs per square yard for this experiment are given in table 11.

TABLE 11.—*Construction and average annual maintenance costs per square yard for experiment 5*

Section	Construction costs			Average annual maintenance costs
	Bituminous material	Labor, supplies, and equipment	Total	
	Cents	*Cents*	*Cents*	*Cents*
A	26.60	7.10	33.70	8.67
B	25.22	5.73	30.95	3.58
C	32.20	9.13	41.33	2.57
D	32.51	8.54	41.05	4.51

2 GALLONS OF TAR PER SQUARE YARD FOUND TO GIVE STABLE MIXTURE

Experiment 6, extending from station 582 to station 794, had 2- and 3-inch mixed bases of sand-clay and tar. The bases were primed with tar, surface-treated with hot and cold-application tars, and covered with tar-treated sand-clay or with crushed stone.

This experiment included five sections in which the bases were sand-clay mixed with tar of 18 to 25 specific viscosity at 40° C. The bases were 2 inches in thickness except that of section B which was 3 inches.

Sections A and B were surface-treated by the enrichment method similar to that employed on experiment 5, using for this purpose the 18 to 25 viscosity tar and treated sand-clay. The surface-treatment of section C consisted of an application of tar of 25 to 35 specific viscosity at 40° C., applied cold, and a cover of 1¼- to ¼-inch stone. Sections D and E were surface-treated in the same manner except that the bituminous material was a hot-application tar.

Experiment 6 lies entirely in rolling country and has good natural drainage except for about 200 feet of section B which borders a swampy area. The subgrade varied considerably in composition, the west portion of section A, the east and west ends of section B, and the east half of section C appearing to have more clay than the remainder of the experimental section. This was quite noticeable both in mixing and in the appearance of the finished mixture. Sections D and E appeared to contain little clay as the untreated material pulverized easily before the tar was applied, coated readily, and was uniform and free from uncoated clay balls when mixing was completed. Sections A, B, and C, on the other hand, required more than the usual amount of mixing, in spite of which a uniform mix was not obtained owing to the presence of many uncoated clay balls.

During the construction of sections A, B, C, and D, mixing was interrupted by rain and additional blading was necessary to dry the mixture. Under traffic the mixture, on those areas that had appeared high in clay content, did not compact into a dense uniform mat but into stratified layers, the surface being considerably marked by irregular vertical cracks.

Sections A and B, for which surface-enrichment was planned, began to dust under traffic before they had compacted. An attempt to enrich the surface of section A while in a dusty condition proved unsuccessful, so the two sections were remixed and relaid. They were then given the surface-enrichment application immediately after initial compaction had been obtained and before dusting could start—a period of about 24 hours.

The enrichment application, amounting to 0.27 gallon per square yard for section A and 0.28 gallon per square yard for section B, was lightly covered with tar-treated sand-clay which had been previously bladed from the mat and windrowed at the sides for this purpose.

Sections C and D were given a light application of 18 to 25 viscosity tar after they had been compacted and before the surface treatment was applied.

Section E varied from the other sections of experiment 6 in that different amounts of tar were used in four portions of the base, to determine, if possible, the most satisfactory amount of bitumen. The section was divided into four equal parts and the amounts of tar used originally were 1.77 gallons per square yard for the first, 2.18 gallons per square yard for the second, and

2.60 gallons per square yard for the third. When these three areas had been mixed and compacted they were given a prime application of 0.33 gallon of tar per square yard. Almost immediately, however, parts 2 and 3 shoved and rutted badly, apparently because of an excess of bitumen. Part 1 appeared lean but remained stable during a 2-week period under traffic. Parts 2 and 3 were remixed and relaid. The behavior of these 3 parts indicated that about 2.00 gallons per square yard should be nearly correct. Application of 2.08 gallons per square yard on the fourth part resulted in a mixture that was stable under traffic. Parts 2, 3, and 4 were primed with one-fourth gallon of 18 to 25 viscosity tar per square yard before the hot tar and stone cover were applied.

Within 2 months after construction sections A and B had become extremely rough and the excessive cracking which had developed gave them a very unsightly appearance. A hard, leathery crust formed on the surface, making it impossible to blade the surface to eliminate the roughness caused by shoving. After a considerable period of time the mixture apparently developed stability and internal movement decreased, but surface smoothness was never obtained to any high degree even after the sections were given a surface treatment and a stone cover in 1931.

Section C was considerably more satisfactory in behavior than sections A and B, but not nearly as satisfactory as sections D and E. The east end of section C required fairly heavy maintenance in its early life, partly because of subgrade failure and partly because of the unstable mat. This portion of the section contained a considerable amount of clay, both in the subgrade and in the mixed base.

Sections D and E were quite satisfactory from the start. Their bases were stable and their surfaces were smooth and generally free from cracking or raveling. Because of its high crown, section E required somewhat more maintenance than section D to remedy edge failure.

In 1931 the entire experimental section was given its first re-treatment which consisted of 0.36 gallon per square yard of the TC grade 5 tar having a specific viscosity of 48.7 at 40° C. and 37 pounds of ¾- to ¼-inch stone per square yard. This treatment considerably improved the condition of all of the sections but did not eliminate entirely the surface roughness of sections A, B, and part of C.

When inspected in March 1934 all of the sections were in need of a re-treatment. Sections A and B were both excessively rough, and on section B an appreciable portion of the base had been replaced by new mixed material to obtain stability.

EXPERIMENT 7 REMAINED IN GOOD CONDITION AND GAVE SATISFACTORY SERVICE

Sections C, D, and E had lost their uniform appearance due to whipping off of the cover stone, but with the exception of a portion of section C all were fairly smooth.

The construction and average annual maintenance costs for experiment 6 are given in table 12. The average annual maintenance costs as given might indicate equivalent behavior of section C as compared with sections D and E; however, at no time in its life was section C as satisfactory as the other two.

TABLE 12.—*Construction and average annual maintenance costs per square yard for experiment 6*

Section	Construction costs				Average annual maintenance costs
	Bituminous material	Cover material	Labor, supplies, and equipment	Total	
	Cents	*Cents*	*Cents*	*Cents*	*Cents*
A	38.84		10.52	49.36	3.10
B	51.96		11.98	63.94	4.18
C	43.91	9.58	9.80	63.29	2.78
D	41.70	9.65	10.96	62.31	2.59
E	37.54	9.58	12.77	59.89	2.84

Experiment 7, extending from station 794 to station 1000, had a 2-inch mixed base of sand-clay and cut-back asphalt. It was sealed with hot asphalt or cut-back and covered with crushed stone.

This experiment covers three sections in which the base was a 2-inch mixture of 85 to 100 penetration cut-back asphalt. The surface treatment was a hot asphalt on sections A and B, and an 85 to 100 penetration cut-back asphalt on section C. All three sections were covered with 1¼- to ¼-inch stone.

The surface and subgrade on this experimental section varied somewhat throughout its 4-mile length but appeared to be of sandier composition than most of the preceding sections. The sand-clay was broken up readily with the blade and the newly exposed, untreated base broke up under traffic and also under the construction equipment so that the resulting mixed base was actually as much as 6 inches thick in the sandiest locations. Mixing was easily accomplished and, when laid down, the mixture compacted readily into a smooth, well-bonded mat that did not dust under traffic. A light prime of 85 to 100 penetration cut-back was applied to sections A and B but not to section C. Sections A and B then received the application of hot asphalt and stone cover, and section C received an application of the 85 to 100 penetration cutback and a stone cover.

The design of section A of experiment 7 was similar to that of section E of experiment 6 in that varying quantities of bitumen were used in the base. The amounts originally applied were insufficient for the east half and excessive on the west half. The section was remixed, adding bitumen to the east half and additional untreated material to the west half. When the mixing was completed the mat compacted and bonded readily under traffic and when surface treated it appeared to be in excellent condition.

Considerable roughness developed on a short curved area at the east end of section B and on two areas of section C. This was caused by a combination of bad subgrade conditions and lean base. These areas were scarified, remixed, and re-treated in 1929.

Except for the failure just mentioned, experiment 7 has remained in good condition and has given excellent service. Surface roughness caused by subgrade settlement gradually developed eventually but no inherent weaknesses, that could not be eliminated by surface treatment, made their appearance. Only one re-treatment has been given since construction, and that was applied to section A in 1932 and to sections B and C in 1931. It consisted of 0.42 gallon of 150 to 200 penetration cutback and 35 pounds of ¾- to ¼-inch stone per square yard for section A, and 0.32 gallon of 85 to 100 penetration cutback and 40 pounds of ¾- to ¼-inch stone per square yard for sections B and C.

The good behavior of this experimental section is reflected in its average annual maintenance cost and in its condition which, in March 1934, showed it to be stable and free from cracking, raveling, or other evidences of impending failure. Its surface roughness could be eliminated by a fairly heavy re-treatment.

The construction and average annual maintenance costs per square yard for experiment 7 are given in table 13.

TABLE 13.—*Construction and average annual maintenance costs per square yard for experiment 7*

Section	Construction costs				Average annual maintenance costs
	Bituminous material	Cover material	Labor, supplies, and equipment	Total	
	Cents	*Cents*	*Cents*	*Cents*	*Cents*
A	28.67	9.58	7.92	46.17	3.21
B	30.84	9.60	8.20	48.64	2.63
C	25.80	9.58	9.88	45.26	3.68

SURFACE ON EXPERIMENT 8 WAS VERY SATISFACTORY AND ECONOMICAL

Experiment 8, extending from station 1000 to station 1087, was a surface treatment of sand-clay with a prime of tar or cut-back asphalt. It was sealed with hot asphalt and covered with crushed stone.

This experiment was included in the project for comparison with the mixed-base experiments and also with similar treatments that were constructed elsewhere in the State upon other types of bases believed at that time more suitable for such treatment.

The sand-clay surface of this experimental section was, in general, more stable than that on the other sections due to a higher percentage of coarse sand. In this respect the west half of the section appeared to be more satisfactory than the east half.

The main difficulty experienced in constructing experiment 8 was in the preparation of the surface for treatment. The road was scarified and shaped with a blade grader to produce a uniform cross-section. Compaction was obtained by traffic and only under favorable moisture conditions. Three times, each just after a rain, the surface was lightly bladed while in a moist condition, removing the blade grader before the surface dried appreciably to prevent the accumulation of loose material that would not bond when dry.

After it had been consolidated as well as possible, the surface was swept with a rotary broom and by hand. After sweeping, it presented a very ragged appearance owing to the many depressions found where sand pockets had previously existed. These depressions were filled with stone before applying the prime.

Approximately 0.3 gallon per square yard of 8 to 13 viscosity tar was applied as a prime, but many small areas were not satisfactorily covered. A light second application of tar, however, successfully covered these areas and gave the surface a uniformly well-primed appearance. The total amount of tar prime used was 0.47 gallon per square yard. As the quantity of light tar on hand was insufficient for priming the entire section, a portion at the east end of the section, stations 1000 to 1026, was primed with 85 to 100 penetration cut-back asphalt at the rate of 0.55 gallon per square yard.

After an interval of 4 to 6 days during which traffic was excluded, the primed base was given an application of 0.38 gallon per square yard of 150 to 200 penetration asphalt applied at 275° to 315° F. and was immediately covered with 60 pounds per square yard of 1¼- to ¼-inch stone. Light rolling followed the spreading of the stone cover and in this operation considerable care was required to prevent breaking the mat.

Rather intensive maintenance was required for the first 2 months until the first re-treatment was applied in December 1927. In spite of this, however, the cost of experiment 8 for the first year, both for maintenance and for the seal, was less than the average for the remainder of the experimental sections. Since the December 1927 treatment, experiment 8 has received only one re-treatment. The portion between stations 1026 and 1087 was re-treated in 1929 and the remainder was re-treated in 1931.

During its life the principal defect of this section has been its surface roughness which, while considerable, was not as pronounced as that of some of the other sections. Roughness was caused by slight subgrade movement, not by failure of the surface mat. Some cracking has occurred more recently but the surface has not raveled or shoved.

Considering its construction and maintenance costs, this experiment has been surprisingly satisfactory and economical. The stability developed by the sand-clay mixture was greater than had been anticipated, and construction of the waterproof surface enable the base to retain this stability. The section weathered the winter of 1933–34, which was an unusually severe one, in excellent shape, in contrast to similar projects nearby. On these latter projects clay-gravel bases with high clay contents had been constructed on the loosely bonded sand-clay surface, and upon these bases surface treatments similar to those of experiment 8 had been constructed. The repeated cycles of freezing and thawing and the effect of moisture on the clay-gravel base resulted in extensive cracking and many areas of complete disintegration of these surfaces. Surface repairs proved inadequate for such failures and the only alternative was removal of the clay-gravel base, substitution of a pre-mixed, sand-asphalt base, and the construction of a new surface. No such repairs have been required on experiment 8. Figure 12, taken 4 years after construction, is typical of the appearance and condition it has retained since construction.

The cost per square yard of constructing experiment 8 were as follows:

	Cents
Bituminous materials	8.91
Cover material	9.58
Labor, supplies and equipment	6.50
Total	24.99
Average annual maintenance cost per square yard	3.54

RESULTS EMPHASIZED IMPORTANCE OF HAVING A STABLE SUBGRADE

Because of progress made in the field of low-cost bituminous construction since this experimental road was built, most of the details of construction and many of the facts established by this experiment are already well known and accepted. However, the great variety of factors covered by the experiment and the fact that it has been under close observation for 7 years justify some discussion of the observations made and the data accumulated during this period.

The discussion is based entirely upon conditions that obtained on this experimental road and consequently the conclusions drawn are not necessarily applicable to

FIGURE 12.—VIEW OF EXPERIMENT 8 TAKEN 4 YEARS AFTER CONSTRUCTION. THIS IS TYPICAL OF THE APPEARANCE AND CONDITION IT HAS RETAINED SINCE CONSTRUCTION.

FIGURE 13.—POOR DRAINAGE RESULTED IN THE UNSATISFACTORY CONDITION OF THIS AREA OF EXPERIMENT 3 NEAR STATION 363. ANALYSES OF MAT AND SUBGRADE FROM THIS AREA ARE GIVEN IN TABLE 7.

other projects where the soils and drainage conditions are materially different. Table 4 shows that the soil on this road is a fine-grained, sandy material containing a large percentage of fine sand and small percentages of coarse sand, silt, and clay. It cannot be safely assumed that with other fine-grained soil materials as, for example, soils of high silt content but deficient in sand, the same results would be obtained in bituminous construction of the character described in this report.

The general belief that the service behavior of any flexible pavement is, to a great degree, dependent upon the character of its supporting subgrade is further confirmed by results obtained on this experimental road. The analyses given in table 7 show the subgrade to have properties characteristic of the A–2, A–3, A–4, and A–6 soil groups. Satisfactory and unsatisfactory surface conditions were found on both A–2 and A–6 subgrades and in most instances these conditions were associated with the drainage provided. An examination of the properties of experiment 3, given in table 7, illustrates quite clearly the effect of drainage. Only one area, that in the vicinity of station 365, continued unsatisfactory for much of the 7-year period, and this area, which was in a slight cut, was poorly drained. Its usual condition, illustrated in figure 13, is in marked contrast to the generally good condition of most of the experiment of which figures 14 and 15 are typical illustrations. Apparently neither the thickness of the bituminous mat nor its inherent stability offset the detrimental effect of poor drainage of its plastic subgrade.

Experiment 8, a thin, surface-treated section on a well-drained, plastic, A–2 soil, was considerably better than the poorly drained sections of experiments 3 and 4–B, although on the latter the bituminous mats were 2 inches and 3 inches thick originally.

The lack of uniformity in the character of the subgrade materials typified by the presence of A–6 soil immediately under the bituminous mat at stations 63 and 440, as well as in a more normally expected position at station 145 as shown in table 7, indicates in a measure the character of the maintenance presumably given the old road. Little information is available concerning previous maintenance. Apparently clay was used to stabilize the more sandy portions of the road and sandy materials were used on those areas where clay pre-

FIGURE 14.—GENERAL VIEW OF EXPERIMENT 3 AT STATION 353, SHOWING THE USUAL CONDITION OF MOST OF THIS EXPERIMENTAL SECTION. ANALYSES OF BITUMINOUS MAT AND OF SUBGRADE ARE GIVEN IN TABLE 7.

dominated. Manipulation of the clay and sand to obtain a uniform surfacing material evidently had not been done.

Two comparisons for which information was desired were obscured by the effect of variations in subgrade. They were the effect of the consistency of the asphaltic cement used in the cut-back materials and the effect of the depth of the mixed bases and surfaces. Experiment 2 included sections in which the only variable in construction methods and materials was the penetration of the asphalt used in the cutback, but at no time during the period covered by this study did this difference in penetration have any apparent effect on the sections. Experiment 5 was designed to study the relative merits of 2- and 3-inch bases but here, too, the subgrade effectively prevented a true comparison.

On the other hand, the condition of the subgrade did provide one opportunity for a comparison that would not have been possible had it been either uniformly good or bad. This was a comparison of the service behavior of the slow-curing oils used in experiments 3 and 4. The construction and maintenance of these two experimental sections have been approximately the same, the only differences being the oils used and the fact that the mat on experiment 3 was 2 inches thick while that on experiment 4 was 3 inches. This fact, however, is believed to have had little bearing upon the performance of these sections. It seemed apparent that the difference in service behavior of the two sections was primarily caused by the characteristics of the oils.

MIXTURE RETAINED HALF OF ITS ORIGINAL VOLATILE MATTER 7 YEARS AFTER CONSTRUCTION

The three types of bituminous materials used in the mixed bases were cold-application materials of relatively low viscosity. The slow-curing oils were not expected to harden greatly or increase in cementitiousness in service. The cut-back asphalts and the 18 to 25 viscosity tar, however, contained volatile material which was expected to be lost during construction or shortly thereafter, leaving a bituminous residue of a consistency sufficiently high for good binding quality. During construction no difficulty was encountered in manipulating and spreading the mixtures or in remixing some of the cut-back sections after a year or two. Neither the tar nor the cutbacks stiffened appreciably except on the immediate surface until considerable time had elapsed. The actual loss of volatile matter during construction was not determined but was apparently much less than had been expected.

FIGURE 15.—ILLUSTRATION OF THE CLOSED TEXTURE CHARACTERISTIC OF MOST OF EXPERIMENT 3. ANALYSES OF MAT AND OF UNDERLYING SUBGRADE AT STATION 353 ARE GIVEN IN TABLE 7.

A sample, whose analysis is given in table 7 under laboratory no. 39362, representing the full depth of the original mixed base containing cut-back asphalt, was taken 7 years after construction to determine whether it still retained any appreciable amount of volatile matter. Upon examination it showed that 18.4 percent of the existing bitumen was volatile matter as determined by an oven test made on the mixture at 325° F. Since the cutback used originally showed a maximum loss of 33.9 percent at 325° F. in the standard oven test, it is indicated that approximately 53 percent of the volatile matter was still present after a period of 7 years. It seems apparent, therefore, that the loss of volatile matter at the surface resulted in the development of a viscous material which, in combination with the fine-grained aggregate, formed a tight seal that effectively prevented the escape of the volatile matter in the binder below the surface. Evidently the rate of hardening of the cut-back asphalt was more dependent upon the manner in which it was used than upon the character of its volatile constituent.

For the conditions existing on this road it is apparent that manipulation of the mixture could well have been continued over a longer period of time. Had this been done, a higher consistency would have been developed by the bituminous material with a corresponding lessening of the effect of the variation in the grading of the mineral aggregate. Later practice has been either to continue manipulation to eliminate as much of the volatile material as possible without leaving the mixture too tacky to spread and compact, or to apply the bitumen in smaller increments and to do considerable manipulation after each application. The latter method is probably better as it would afford the engineer a better opportunity of making a final decision as to the correctness of the mixture.

The penetration of the asphalts used in the cut-backs ranged from 85 to 180. The effect of this difference in penetration was not apparent either on the relative durability of the material or upon the re-treatments required. In all cases other factors so overshadowed the difference in the cut-back asphalts that their comparative values could not be established.

The slow-curing oils differed considerably from the cut-backs in their characteristics and behavior as a binding medium. As shown by the analyses, given in table 1, they contained relatively small amounts of volatile matter as determined by the standard oven test and the residues from this test were fluid. The behavior of experiment 3 was considerably different than that of experiment 4 due to the characteristics of the oils used. The mixture of experiment 3 did not develop the brittleness and raveling typical of experiment 4. Analyses of the oils used in the two experimental sections likewise showed a considerable difference in characteristics. Oil A, which was furnished as a straight reduced material, had a low specific gravity and high solubility in naphtha. Oils B, C, and D had relatively high gravities and low solubilities in naphtha, indicating that they were more highly cracked in the process of manufacture than was oil A, or that they contained greater percentages of cracked material.

TAR MIXTURES ATTAINED GREATER STABILITY THROUGHOUT DEPTH THAN DID CUT-BACK MIXTURES

In the re-treatment of experiments 3 and 4 in 1928 and 1933 it was intended to use the same type of oil that was used in the construction of experiment 3, but analysis of the oil used showed it to have characteristics more nearly like those of oils B, C, and D, indicating that it, too, was a cracked oil. Analyses of the oils used in the re-treatment of sections B and C of experiment 4 in 1930 are not available but were supposed to be the same as those of the oils used in their original construction. Considering the characteristics of the oils used in the re-treatments of 1928 and 1933, it is most likely that the oils used in 1930 were not greatly different from those used originally. The difference, if any, was at no time apparent in the behavior of sections A, B, and C.

Except for crusting of the immediate surface, experiment 3 continued more malleable throughout its life than did experiment 4. The stabilities developed by the mixtures in their early life were comparatively low and while they increased slowly, that of the mixture of experiment 4 increased more rapidly than that of experiment 3. The surface of both experimental sections was abraded somewhat by traffic and the loosened material dissipated, but experiment 3, because of its higher plasticity, in general, suffered less from mutilative traffic and, when disturbed, rebonded much better than did experiment 4. The latter experimental section, however, appeared to be less affected by moisture.

On sections A and D of experiment 5, oil E, which was similar in character to oil B, was used for the surface enrichment of the mixed base in which a cut-back asphalt had been used. In this case the mixed base developed a certain degree of hardness while the upper portion, enriched with the slow-curing oil, remained more plastic. This resulted in considerable shoving and displacement of the surface which soon became so rough that re-treatment with cut-back asphalt and stone cover was necessary to restore a satisfactory degree of smoothness. Figure 7–A illustrates the rough condition of section 5–D caused by surface enrichment with slow-curing oil.

On experiment 8 a tar of 8 to 13 specific viscosity and a naphtha cut-back asphalt were used for priming the sand-clay base prior to surface treatment. Rapid-curing material such as cut-back asphalt is seldom used for priming purposes and it was used here only because of a shortage of tar prime. Little difference in behavior of the areas thus primed has been apparent so far. The area on which the cut-back was used, however, was sandier and more open than the remainder of the section, which probably accounts for the penetration of the cutback.

The 18 to 25 viscosity tar used in the mixed base of experiment 6 and in the surface enrichment of sections A and B of that experimental section was comparable in some respects to the cut-back asphalts. It was a low viscosity, cold-application material containing a considerable amount of volatile matter and, upon losing this volatile matter, it developed a residue comparable with those of the cut-back asphalts in consistency. This change in consistency, while somewhat slow, extended through the full depth of the base and was not confined to the surface alone as in the case of the cut-backs. As shown in table 7, stability tests made on samples taken 7 years after construction show that the stability of the mixture 1 and 2 inches below the surface is relatively high in comparison with the top 1-inch of the tar mixtures, but in the cut-back asphalt mixtures the corresponding stability is substantially less for portions of the mixture below the surface than at the top.

Where the 18 to 25 viscosity tar was used in the surface enrichment of sections 6–A and 6–B it readily lost sufficient of its volatile matter to produce a hard crust which, however, was relatively thin. This same bituminous material within the mixture did not lose its volatile constituents so rapidly and as a result the base remained relatively plastic. As a consequence, considerable shoving and corrugating of the mat and cracking of the surface crust occurred. This condition continued in gradually decreasing intensity for approximately 4 years or, apparently, until the bitumen in the base had developed a consistency sufficiently high to provide the stability required. When stability had been developed as indicated by a cessation of mat movement, the sections were given the long-needed surface treatment which had been delayed for fear of retarding the slowly increasing stability.

BOTH HOT- AND COLD-APPLICATION MATERIALS USED TO SURFACE-TREAT MIXED BASES

The 25 to 35 viscosity tar and the hot tar were used as binders in the surface treatment of sections 6–C, D, and E to provide information on the relative merits of cold- and hot-application materials. At the time the 25 to 35 viscosity grade was thought to approach the maximum viscosity for cold application and though it may be considered to have been reasonably satisfactory, later experience has shown that considerably higher viscosity materials can be used advantageously. It will be recalled that in the re-treatment given experiment 6 in 1931 a tar of 48.7 viscosity at 40° C. was used. No difficulty was encountered in applying this material or in road-mixing it with the cover stone. In spite of the relatively high viscosity of the tar, approximately 10 days elapsed before the surface had stiffened sufficiently to resist picking up under traffic. This was believed due to the low rate of loss of volatile matter.

Analysis of the 25 to 35 viscosity tar is not available but it may be reasonably assumed that, like the 18 to 25 and the 48.7 viscosity tars used in the base construction and in the re-treatment of 1931, it contained some volatile matter which when lost would leave a base material sufficiently viscous to hold the cover stone. The hot material, on the other hand, would be expected to lose very little through volatilization, the fluidity desired for application purposes being obtained by heating. This basic difference between the hot- and cold-application binders was reflected in their behavior.

In surface treatment of the mixed bases both hot- and cold-application tars and asphalts were used with mineral covers. The hot-application materials, because of their high viscosity, did not penetrate into the mixed bases but remained on the surface, adequately holding the cover material to form a hard mat which received the wear of traffic.

The cold-application materials, on the other hand, penetrated into the base in varying amounts depending upon their viscosity and the denseness of the base. Penetration in any considerable amount resulted in softening of the mixed base with consequent reduction in its stability. Penetration also permitted the cover material to become embedded in the base, forming a mastic which received the wear of traffic. When less penetration occurred, softening of the base was not so pronounced, but the loss of bitumen by penetration as well as by evaporation reduced the amount available for holding the cover materials, which were thereby subject to displacement under traffic.

Where the mixed mat was well compacted before the surface treatment was applied, the cold-application materials did not penetrate and were satisfactory. An illustration of this is experiment 2–A, which has a record of excellent service behavior at relatively low cost.

In addition to the possibility of loss by penetration, evaporation losses also reduced the net amount of bitumen correspondingly. Increasing the amount of bitumen and modifying the method of applying the treatment might have offset these losses and also might have prevented penetration in some instances. It appears advisable and more practical, however, that the surface treatment material used should be of such viscosity that it will not penetrate into the base or else that the method of applying the treatment be such that penetration is reduced to a minimum.

The amount of bitumen used in the mixes of the different sections varied considerably, as shown in table 5. Some of this variation was planned, as in the case of experiments 6–E and 7–A, but in all other sections it was the result of the method of construction.

Formulas for determining the amount of bitumen to use with aggregates of a given grading have been developed more recently and used satisfactorily by a number of States. Such formulas apparently have very narrow limits of application since none is used widely outside of the State in which it was developed, and in most cases where used by other States some modification of the formula has been found necessary. In addition, the formulas are applied to aggregates whose grading is uniform and, regardless of the correctness of the formula, uniform mixtures should be expected.

IMPOSSIBLE TO DESIGN MIXTURES BY EMPIRICAL FORMULAS

With the exception of experiments 3, 4, 5, 6–A, and 6–B, the mixed sections served as bases, surface-treated with bitumen and mineral cover; consequently, they were designed for stability primarily and as a result contain less bitumen than they would have if they had been intended to serve as wear-resisting surfaces. Comparison of their bitumen content with any empirical formula would therefore serve no useful purpose. The mixed sections designed to carry traffic without any additional wearing surface do offer an opportunity for comparison of the percentage of bitumen actually used with that required by theoretical formulas and curves, although the variation in grading of the aggregate and the frequency with which this variation occurred would have made the application of an empirical formula futile in design.

On this project, experiments 3 and 4 were of uniform composition throughout their depth, while experiments 5, 6–A, and 6–B were leaner in the lower portion and enriched in the upper portion but were not covered with wear-resisting mineral cover. To present such comparison as can be made, the analyses of samples taken from the non-surface-treated sections are retabulated in table 14 for convenience. The data given in this table indicate that neither an empirical formula nor a numerical stability value, which is a variable characteristic, should be arbitrarily selected because of its successful use under other conditions or with bituminous materials of different characteristics. Table 14 shows that considerable variation in stability is found when different bituminous materials are used and also that numerical stability value alone does not indicate probable service behavior.

TABLE 14.—*Comparison of the kind and quantity of bitumen with stability of bituminous mixtures*

Sample no.	Experiment no.	Type of bitumen used	Hubbard-Field stability at 77° F.			Amount of bitumen [1]			Remarks [3]
						Extracted from field samples	Required by—		
			Maximum	Minimum	Average		Surface-area method	Nebraska formula [2]	
			Pounds	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	
39359	3	Slow-curing oil	1,620	1,550	1,585	7.64	7.25	5.34	Good area, stable when sampled; remains so in cool weather. Ruts slightly in warm weather but irons out under traffic. Stability appears adequate.
39358	3	do	1,730	1,730	1,730	7.30	7.52	5.58	Poorly drained area in bad condition. Behavior in dry weather same as above.
39357	3	do	2,910	830	1,870	10.14	7.30	5.51	From a cracked area affected by moisture. Service behavior good. Stability appeared adequate when sampled.
39356a	4–B	do	270	40	155	10.14	7.17	5.21	New mixture on old mat; has no resistance to displacement except in cool weather. Stability when sampled was inadequate.
39356b	4–B	do	3,050	2,000	2,525	10.25	7.57	5.67	Old mat below sample above. Stable except in very hot weather. Dusts under traffic. Stability (against shoving) adequate when sampled.
39355	4–C	do	940	700	820	7.53	7.16	5.34	Service behavior same as above. Stability when sampled was adequate.
39354	4–C	do	1,160	940	1,045	11.35	7.40	5.52	Same as above.
39362	5–C	Cut-back asphalt	5,400	2,940	4,170	8.35	9.15	6.54	Retains stability irrespective of temperature. Continues in excellent condition except for edge failure. Stability adequate when sampled.
39361	6–A	18–25 viscosity tar	5,575	3,640	4,607	7.53	7.60	5.75	Stability accompanied by dusting, increased with age. Surface rough, resulting from early movement. Stability adequate when sampled.
39360	6–B	do	5,710	4,525	5,232	9.53	6.90	5.12	Behavior and condition same as above.

[1] In terms of dry aggregate.
[2] $P=0.02a+0.04b+0.06c+0.12d$ when:
P = percentage of bitumen.
a = percentage of aggregate retained on No. 50 sieve.
b = percent passing No. 50 and retained on No. 100 sieve.
c = percent passing No. 100 and retained on No. 200 sieve.
d = percent passing No. 200 sieve.
[3] Also see table 7.

It is apparent therefore that experience, excellent judgment, and great care on the part of the engineer are of utmost importance in the construction of road-mixed surfaces under conditions characteristic of this road.

For fine-grained, poorly graded aggregates such as were found on this road, the range in bitumen content between mixtures sufficiently rich to resist abrasion without shoving and those whose richness results in shoving is very narrow. Because of this it was practically impossible to obtain a satisfactory, stable, wear-resisting mat without surface treatment. This was tried on experiments 3, 4, 5, 6–A, and 6–B and was only partially successful.

On experiment 3, when the mat was rich enough to resist abrasion it displaced under traffic, especially in warm weather. However, it retained its malleability, and such surface irregularities as occurred were readily ironed out by traffic. As the viscosity of the oil increased because of lower air temperatures or by oxidation caused by weathering, the resistance of the mat to slight movements increased and was usually accompanied by dusting. Addition of the same type of oil eliminated dusting, but, at the same time, reduced the ability of the mat to resist movement.

The behavior of experiment 4 was similar to that of experiment 3, although here greater stability as well as increased dusting and raveling were characteristic. The two sections of experiment 5, on which the slow-curing oil was used, were unsatisfactory without surface treatment because of their inability to resist displacement. The other two sections of experiment 5, on which a rapid-curing material was used in surface enrichment, continued the most stable of the sections not surface-treated. The mats were firm and hard, and did not dust appreciably under traffic. They were rather rough, however, and their edges suffered from mutilative traffic. Sections 6–A and 6–B, which were surface enriched but not surface treated, were unsatisfactory also. The amount of bitumen required to prevent dusting produced a mixture that shoved considerably and was excessively rough.

Comparison between the surface-treated bases in general with the sections not so treated demonstrates the advisability of constructing a rather lean mat of adequate stability and upon it constructing a wear-resisting surface. This method of improving the loosely bound, sand-clay roads such as were found on this road has been used by the State with considerable success on a rather extensive mileage.

MIXING OF RE-TREATMENTS GAVE BEST RESULTS

With the exception of six sections of experiment 2, all sections that were surface-treated were covered with crushed granite 1¼ to ¼ inch in size. The exceptions were sections 2–B, 2–E, and 2–H on which pea gravel was used, and 2–C, 2–D, and 2–I on which local pit-run sand was the cover material.

One of the pea-gravel sections was resurfaced with stone in its earlier life but the necessity for re-treating was not caused by any failure of the original cover material, and stone was used in the re-treatment merely as a matter of convenience. Although the gravel cover did crush somewhat under the roller and under traffic, no failures directly attributable to its use were apparent.

The sand-covered sections were re-treated early in their life and, while subgrade conditions and unstable mixed bases were the main causes for reconstruction and re-treatment, the use of sand as a cover also contributed greatly to the failure of these sections. The same low-viscosity, cold-application material used in the mixtures was used as a seal in combination with the sand in surface treatment, with the result that the sand

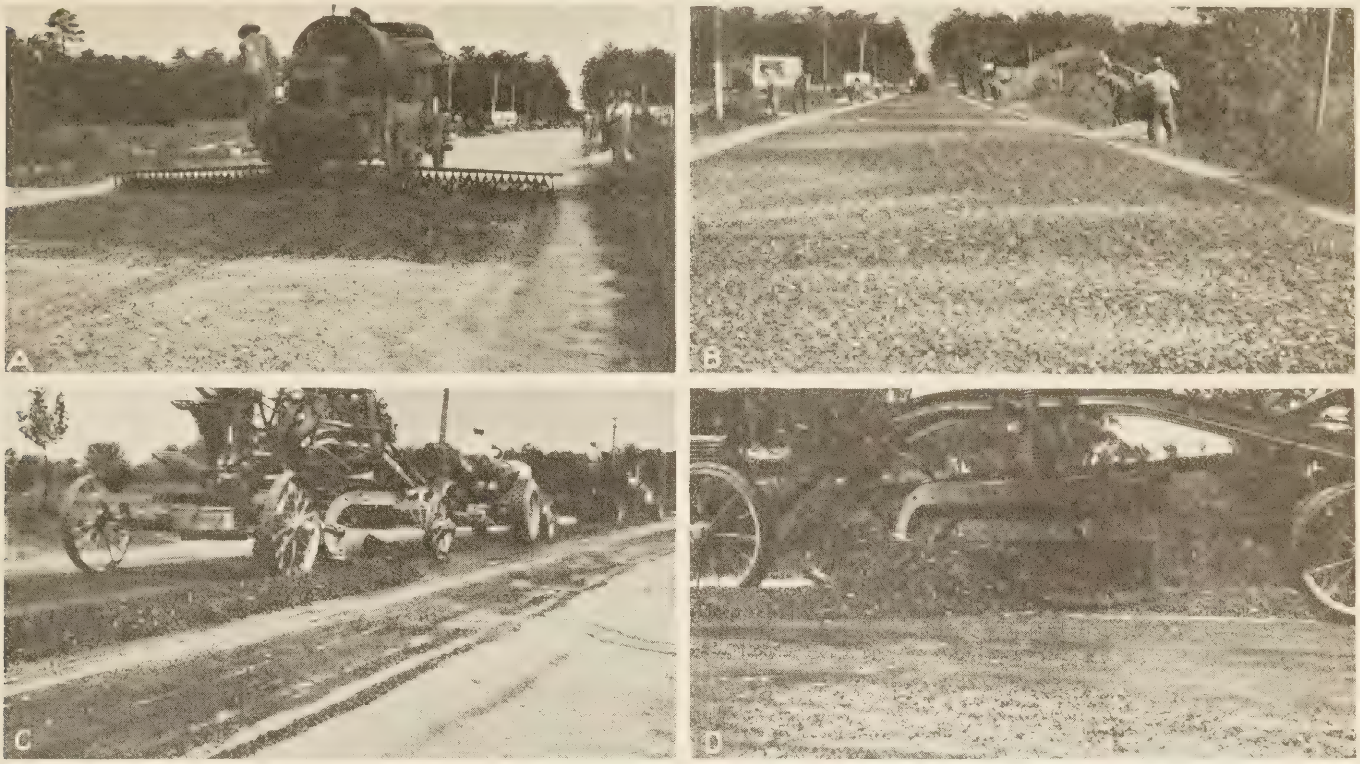


FIGURE 16.—STEPS IN THE APPLICATION AND MIXING OF A RE-TREATMENT. A, APPLYING BITUMEN. END NOZZLES WERE TURNED 90° TO OBTAIN HEAVIER APPLICATION AT THE EDGES. NOTE THAT SOME COVER MATERIAL HAS BEEN SPREAD PRIOR TO APPLYING BITUMEN. B, SPREADING COVER MATERIAL IMMEDIATELY AFTER APPLYING THE BITUMEN. C, MANIPULATING COVER MATERIAL AND BITUMEN IN MIXING THE RE-TREATMENT. D, MIXING THE RE-TREATMENT. VARIABLE APPEARANCE RESULTS FROM SURFACE IRREGULARITIES. BLADE PICKS UP COVER MATERIAL FROM HIGH SPOTS BUT CANNOT REMOVE IT FROM DEPRESSIONS, SO THIS WORK IS DONE BY HAND.

became a part of the mixed base instead of serving as a protection against traffic wear. Three types of failure developed in these sections; pot-holing, edge failure by abrasion under traffic, and excessive roughness caused by loss of stability in the mixture due to the increase of bitumen.

Section 2–I was covered with stone 1 year after construction and sections 2–C and 2–D were similarly treated a year later. This treatment eliminated the failure not caused by subgrade conditions.

In the re-treatments following construction, crushed granite, usually three-fourths to one-fourth inch in size, was used except on section 2–B on which the gravel cover has been retained.

In applying re-treatments to the various sections, effort was made to continue the type of experiment unchanged as long as possible, or until it was demonstrated that no useful purpose would be served by continuing it unchanged and that better service could be obtained by changing it. In the early life of the experimental sections the re-treatments consisted of applying the same type of bituminous material and of cover that were used in the original construction. The inability to differentiate between the merits of the various grades of cut-back and the unsatisfactory results obtained from using sand as a cover soon resulted in the adoption of a single grade of cut-back and the use of stone only as cover material except in the case of section 2–B.

The majority of re-treatments were applied to eliminate surface roughness caused primarily by base and subgrade settlement and by movement of the richer mixes, especially during their early life. In applying re-treatments the cover materials were spread by hand and, in the earlier treatments, they were broomed by hand and by dragging to obtain a smooth surface. Later, however, as subgrade settlement increased with a correspondingly greater surface roughness, the plan of mixing and spreading the bitumen and cover used in re-treatment with blades or drags was introduced. This method, which was an innovation at least in this part of the country, was very satisfactory and the resulting surfaces were smooth, but obviously not uniform in depth. Where the existing mat was remixed prior to applying the surface re-treatment, mixing of the bitumen and aggregate composing the treatment was not done. Where the existing surface was not to be disturbed the blade-mix method was always used.

Some advantages of using the blade-mix method, which are not obtained without using it, are the elimination of pools of bitumen in low spots, a more uniform mixture, little or no loss of cover stone, and a uniform-appearing surface on which traffic will travel over the full width. Where mixing is not done, considerable cover stone is lost by traffic even though the surface has been rolled, and traffic tends to travel in a single lane. Figure 16 illustrates the method of applying the later re-treatments to the sections of this road. This method is used almost entirely by the State at the present time. The surface appearances of mixed and unmixed re-treatments are shown in figures 17 and 18.

FIGURE 17.—A, TYPICALLY UNIFORM APPEARANCE OF A MIXED SURFACE RE-TREATMENT. B, APPEARANCE OF A NEWLY RE-TREATED SURFACE THAT WAS NOT MIXED. ON SUCH SURFACES TRAFFIC HAS A DECIDED TENDENCY TO TRAVEL IN A SINGLE LANE.

TYPE OF EXPERIMENT HAD NO DIRECT RELATIONSHIP TO MAINTENANCE COST

Maintenance of the roadway proper consisted of such patching and replacements as were necessary and the application of re-treatments to the old or reconstructed base and surface. This work is included in the maintenance costs given herein which do not, however, include such work as the construction and maintenance of shoulders, side ditches, or the installation of supplementary drainage fixtures.

With the exception of experiments 3 and 4, the experiments were not designed for machine maintenance, and repairs were made by patching and by re-treatment. Experiments 3 and 4 were included to provide a comparison not only of the oils used but also of methods of maintenance. The mats of these two experimental sections remained relatively malleable in comparison with those in which cut-back asphalts and tars were used, but because of surface crusting caused by hardening of the bitumen at the surface they were not suited to machine maintenance, contrary to expectations. Under favorable conditions the surface could be lightly cut for smoothing purposes, though the material thus cut from high spots did not bond in the depressed areas but was whipped from the surface by traffic. Continual blading to maintain smoothness on such surfaces could only result in the dissipation of the entire mat. The alternative to excessive planing was remixing of the entire mat with or without the addition of bitumen.

Since the period covered by the cooperative study of this experimental road, considerable success has been attained in lessening the effect of certain unfavorable subgrade conditions by building a new sand-cutback-asphalt mat over the old surface. The depth of the new mat is varied from 3 to 8 inches depending upon the condition of the subgrade and old surface.

Costs of the experimental sections, both for construction and for maintenance, are given in table 6. In considering these costs it should be remembered that the old road had been maintained as a sand-clay project whose behavior has already been described and also that supplementary drainage had not been provided, nor had any grade lines been established. Work of this character which has been done since construction, such as installing French drains and pipe, and banking curves, has necessitated additional patching and the use of extra surfacing materials, and as a result has had some effect on the cost of maintenance. The shortness of the sections and the variety of materials used both in construction and early maintenance also added to the costs.

It might be expected that the maintenance cost would be about inversely proportional to the construction cost. Such, however, was not the case nor did the type of experiment bear any direct relationship to the maintenance cost. Experiments 1–B, 7–A, and 7–B were identical in construction, differences in cost being due primarily to length of haul. The maintenance cost of experiment 1–B, however, is 2.7 and 3.3 times that of 7–A and 7–B, respectively, and its total cost for the period is more than 50 percent greater than these two in spite of the fact that they cost approximately 50 percent more to construct. This difference in maintenance cost can be attributed almost entirely to the additional maintenance required on experiment 1–B because of subgrade failure. The low maintenance cost of experiment 6 cannot be assumed to indicate continued satisfactory service for, as stated previously, the instability of the mixture on this experiment made it inadvisable to apply surface treatments which should have been applied to eliminate the surface roughness that was characteristic of the experiment throughout most of the period.

CONSTRUCTION AND RE-TREATMENT OPERATIONS DID NOT INTERFERE WITH TRAFFIC

Sections A, F, and G of experiment 2 were identical except for the consistency of the base asphalt used in the cut-back. Sections B, E, and H, and C, D, and I were alike in the same way. The difference in maintenance cost between A, F, and G, represents approximately the differences in subgrade conditions, and the same applies also to sections B, E, and H. Sections D, E, and F were the same except for the cover materials which were sand, gravel, and stone, respectively. Subgrade conditions appeared about the same on sections D and E and were better than on F, and the differences in cost fairly well reflect the differences in amount of surface maintenance required.

Experiment 8, the double surface-treatment constructed on sand-clay, was maintained at a relatively low cost in spite of its low construction cost. The subgrade soil on this experiment, contrary to early expectations, proved quite satisfactory for the type of construction used because the drainage was apparently adequate.

Another item entering into the cost of maintenance but not indicated by the figures alone was the additional work done in superelevating some of the curves, nor is the actual condition of the sections from day to day indicated by a study of the cost figures. Some sections were decidedly smoother than others, some were rather rough most of the time, and some, such as experiments 3 and 4, continued in a loose condition for some time after re-treatment and, even after they had become compacted, became soft during hot weather. All such points must receive consideration in any attempt to evaluate the different sections from the standpoint of cost and adequacy.

The experimental road, at the time of its completion, did not connect with or touch any part of an improved highway system with all-weather surfaces. The traffic carried by the road prior to construction was mostly local, a fair proportion of which was horse-drawn vehicles carrying from light to relatively heavy loads. Some motor vehicles used the road, but few trucks or busses. The last traffic count, taken before the experimental sections were constructed, showed the road to be carrying 486 vehicles daily. One year after construction it was carrying an average of 559 vehicles daily.

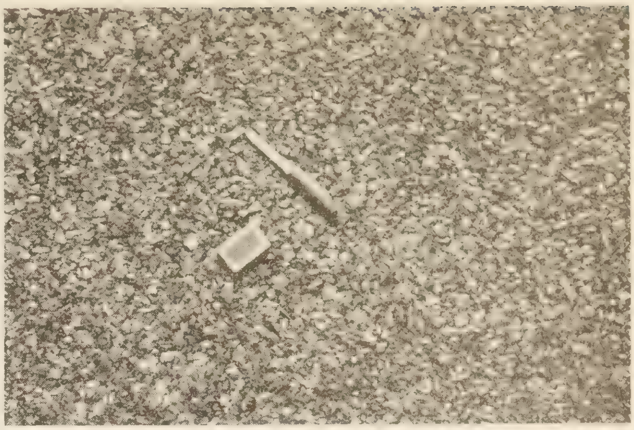
With the gradual improvement of highways in this area other satisfactory travel routes became available for both local and through traffic. Despite this fact, however, the 1935 count shows a considerable increase in traffic since construction of the project. In addition it shows the relatively heavy traffic carried during the summer months when the stability of the various sections is presumably the lowest. Differentiation is also made between the traffic carried by the eastern and western portions of the road. The eastern portion extends from Homewood to Conway, is a part of both United States Highways Nos. 501 and 701, and embraces experiment 1 and about half of 2–A. The western portion of the road extends from Homewood to Gallivants Ferry, and is a part of United States Highway No. 501 only. The average daily traffic recorded for 1935 is shown in table 15.

TABLE 15.—*Daily average traffic carried by the experimental road*

Portion represented	Daily average traffic for 1935	Daily average traffic for June, July, and August 1935	Daily average traffic, remainder of 1935
	Number	*Number*	*Number*
Conway-Homewood	977	1,087	942
Homewood-Gallivants Ferry	558	701	511

The fact that the road surface is still in service and is in better condition generally than at any previous time has demonstrated the practicability of correcting, by subsequent maintenance and retreatment, many errors made initially in the choice of materials or in the methods employed. In effect, the road has been built by stage construction, with the maintenance and each re-treatment adding something to the permanent improvement of the road structure. For this reason, therefore, an appreciable part of the accumulated maintenance cost might be more properly charged on the side of construction.

Another feature merits special attention. During the construction period and also while the re-treatments were being applied, traffic was never seriously interfered with and was only slightly inconvenienced at the most. This fact is of no small importance when the matter of detours is considered, especially in localities where the topography is such that detours not only are expensive to provide and to maintain but may become traffic hazards of decided proportions. So far as the experimental project is concerned, passing traffic not only was not detrimental, but during construction served the very useful purpose of providing compaction for the mixed mats and in so doing made it possible more accurately to determine the correctness of their proportions.



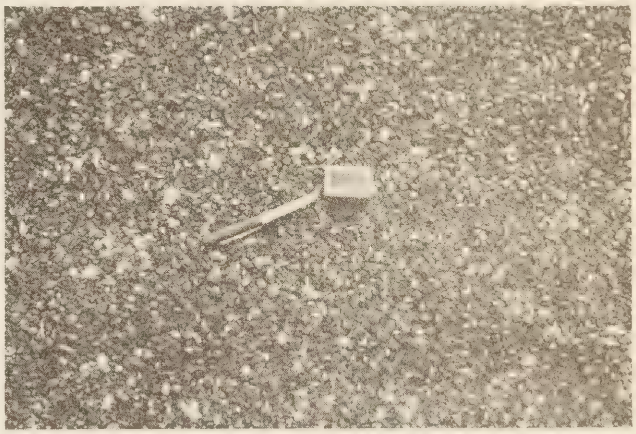


FIGURE 18.—APPEARANCES OF SURFACES OF MIXED RE-TREATMENTS. A, AGGREGATE IS ¾- TO ¼-INCH STONE. B, AGGREGATE IS PEA GRAVEL.

CONCLUSIONS

The facts that appear to have been established during the period covered by this report may be summarized as follows:

1. The serviceability of the experimental surfaces which comprised this project was more greatly affected by the character of the subgrade than by the type of bituminous surface.

2. Failures caused by unsatisfactory subgrade conditions were not eliminated by repairs to the bituminous bases and surfaces but by the removal of the unsatisfactory subgrade materials or by providing adequate drainage.

3. Provision of a substantial subbase prior to construction of the bituminous mat will reduce considerably the cost of maintenance, which is a continuous cost.

4. The surface portions of loosely bonded sandy soils containing little or no clay were treated with a bituminous binding material to form bases satisfactory for thin bituminous wearing surfaces.

5. For loosely bonded, poorly graded, fine-grained aggregates the bituminous material must provide the stability lacking in the aggregate.

6. Manipulation of mixtures containing low-viscosity, cut-back materials should be continued until a considerable portion of the volatile matter has been dissipated.

7. The consistency of the bituminous material used in surface treatment exclusive of the priming application should be such that it will not penetrate into the base, or the method of applying the treatment should be such that penetration is reduced to a minimum.

8. Slow-curing oils that retained their fluidity for a considerable period of time did not compensate for a lack of mechanical stability in the fine aggregate but did produce mixtures that remained plastic under traffic and that, when remixed, readily rebonded with or without additional oil.

9. Slow-curing oils whose fluidity decreased because of weathering developed some binding property but produced mixtures that became brittle and subject to dusting under traffic, and did not rebond without additional oil.

10. With fine-grained, poorly-graded aggregate it was difficult to obtain a bituminous mixture that was sufficiently stable and at the same time would withstand abrasion under traffic.

11. Mixtures of the type used on this road that were sufficiently stable to resist shoving proved more satisfactory when protected with a wear-resisting surface than those that were sufficiently rich to resist traffic abrasion without a protective covering.

12. In re-treatment, a higher degree of smoothness was obtained by machine mixing and spreading the bitumen and aggregate than by hand spreading and brooming alone.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF DECEMBER 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 5,208,287	$ 51,600	$ 25,800	9.0	$ 697,081	$ 348,540	20.1	$ 730,700	$ 365,350	35.3	$ 4,468,597
Arizona	3,564,709	1,845,199	1,436,431	102.5	1,045,703	812,377	38.8	276,405	194,359	6.9	1,121,542
Arkansas	4,275,929				470,883	470,465	11.8	1,951,873	1,950,625	98.3	1,854,839
California	9,508,671	5,088,641	2,926,297	138.8	8,786,655	5,039,277	212.8	1,585,854	912,613	46.6	630,484
Colorado	4,575,144	3,314,813	1,767,167	129.1	2,977,467	1,634,259	108.0	1,224,055	696,403	49.1	477,315
Connecticut	1,582,913	501,875	250,937	9.5	709,601	352,598	9.4	284,230	141,950	4.0	837,428
Delaware	1,218,750	305,920	152,960	30.3	414,598	201,754	11.8	360,874	167,257	13.0	696,780
Florida	3,315,558	826,514	407,878	27.5	598,555	299,273	19.3	1,476,200	738,100	42.6	1,870,307
Georgia	6,336,443	938,571	433,798	72.1	2,709,348	1,345,054	136.6	643,033	321,501	31.2	4,236,089
Idaho	3,065,304	2,478,020	1,474,863	250.6	900,256	538,712	58.4	759,995	454,626	40.7	597,103
Illinois	10,325,922	6,685,740	3,334,610	124.9	5,763,051	2,847,051	116.4	3,999,445	1,976,570	111.9	2,167,691
Indiana	6,184,258	5,149,031	2,567,906	167.8	2,620,352	1,309,438	73.0	2,710,454	1,354,808	71.5	952,105
Iowa	6,466,628	7,020,566	3,340,862	466.7	2,954,783	1,476,205	113.8	2,324,349	1,124,024	68.7	525,537
Kansas	6,631,085	2,987,075	1,492,735	606.4	4,679,106	2,313,100	376.0	2,402,395	1,201,174	123.2	1,624,076
Kentucky	4,611,955	2,213,018	1,081,477	142.2	1,001,780	500,890	36.3	830,608	415,303	29.2	2,614,285
Louisiana	3,557,930	1,780,307	887,861	62.6	886,284	443,140	31.5	870,287	430,845	17.6	1,796,084
Maine	2,177,197	1,904,831	951,618	58.7	799,888	399,944	18.5	484,280	242,140	14.9	583,495
Maryland	2,050,870				924,363	462,146	15.3	587,674	293,837	8.5	1,294,887
Massachusetts	3,485,364	333,935	166,968	3.1	4,432,049	2,166,024	20.3	487,486	243,742	2.3	908,630
Michigan	7,668,768	8,396,486	4,180,672	319.5	5,732,812	2,866,406	136.5	968,000	484,000	29.2	137,690
Minnesota	6,849,307	8,155,385	3,811,905	532.1	2,122,228	1,061,114	117.8	1,570,604	785,302	51.2	1,190,986
Mississippi	4,387,636				768,840	384,720	45.2	937,771	468,785	55.9	3,534,131
Missouri	7,601,200	3,992,349	1,992,287	435.8	6,452,361	3,225,855	240.3	2,695,727	1,337,179	119.7	1,045,879
Montana	5,122,333	3,760,971	2,105,635	384.1	2,616,105	1,464,757	172.3	649,237	325,316	29.2	1,226,625
Nebraska	5,167,930	2,740,846	1,368,005	170.2	2,902,737	1,456,951	288.5	6,602	3,301		2,339,674
Nevada	3,189,479	1,448,617	1,249,457	269.5	691,419	594,683	14.3	9,600	8,300	.5	1,337,039
New Hampshire	1,218,750	857,796	422,345	24.8	182,389	90,742	2.3	10,550	5,275		700,388
New Jersey	3,352,469	2,198,966	1,099,332	30.4	2,569,048	1,207,229	29.0	19,989	9,995		1,035,914
New Mexico	3,990,023	3,167,008	1,947,138	265.7	1,955,831	1,186,499	103.4	497,684	302,687	26.2	553,699
New York	12,306,710	7,169,115	3,528,507	148.4	13,790,944	6,817,222	233.7	3,924,360	1,736,785	42.0	224,196
North Carolina	5,879,466	2,232,465	1,115,370	299.2	2,748,112	1,362,658	215.6	1,920,000	900,300	83.0	2,501,138
North Dakota	3,918,269				384,820	204,581	.4				3,713,688
Ohio	9,131,204	2,334,794	1,166,992	40.9	6,019,220	2,846,496	59.9	798,710	367,355	11.9	4,750,361
Oklahoma	5,884,927	2,435,519	1,264,426	82.3	2,011,130	1,054,588	79.2	450,796	236,891	14.8	3,329,021
Oregon	4,089,711	2,708,655	1,636,974	101.6	2,689,102	1,593,680	113.6	781,181	453,691	21.8	405,366
Pennsylvania	10,695,448	6,019,128	3,009,119	101.6	7,687,391	3,835,761	105.7	2,817,007	1,401,319	46.2	2,449,249
Rhode Island	1,218,750	213,888	106,944	3.4	560,780	280,390	5.3	329,667	164,834	2.3	666,583
South Carolina	3,381,337	176,882	80,000	12.9	3,893,703	1,612,170	251.4	1,341,443	495,000	110.6	1,194,167
South Dakota	4,078,647	1,396,263	784,004	188.6	160,979	99,019	43.4	783,483	429,540	46.9	2,766,084
Tennessee	5,268,270	2,170,243	1,082,992	94.2	579,456	289,723	19.1	809,980	404,990	28.2	3,490,565
Texas	15,548,821	10,486,420	5,227,704	604.0	5,308,788	2,651,430	252.5	6,055,373	2,964,628	371.7	4,705,059
Utah	2,826,960	1,992,673	1,426,511	137.9	779,689	532,715	51.3	327,491	237,761	22.0	629,972
Vermont	1,218,750	1,323,337	659,042	62.9	763,394	354,748	20.2	104,514	52,250	4.3	152,710
Virginia	4,559,200	2,427,708	1,211,498	93.7	2,239,553	1,119,770	109.7	1,527,537	763,768	34.2	1,464,163
Washington	3,904,738	3,629,567	1,908,735	148.1	2,195,186	1,153,071	84.8	539,271	282,900	5.3	560,031
West Virginia	2,716,754	477,989	238,995	28.0	1,124,522	562,249	32.0	692,967	346,484	15.9	1,569,027
Wisconsin	6,090,504	4,102,133	1,968,299	164.7	3,833,485	1,862,474	129.5	802,883	400,385	18.7	1,859,347
Wyoming	3,121,972	2,830,630	1,741,663	367.6	1,090,246	665,987	125.1	413,860	254,870	46.8	459,452
District of Columbia											
Hawaii	1,218,750				537,793	265,921	9.8	421,060	210,195	8.4	742,634
TOTALS	243,750,000	132,271,489	69,034,719	7,513.9	127,763,866	65,663,856	4,519.9	56,197,544	29,059,313	2,062.4	79,992,112

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF DECEMBER 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115	$ 2,419,252	$ 2,418,952	79.6	$ 1,617,853	$ 1,617,853	58.7	$ 34,000	$ 34,000		$ 80,310
Arizona	2,569,841	2,488,635	2,174,659	161.8	565,900	339,234	27.2				55,948
Arkansas	3,352,061	2,388,448	2,370,461	242.3	886,651	884,849	104.8	55,329	55,221	11.9	41,529
California	7,747,928	4,973,493	4,790,066	201.8	2,899,548	2,878,028	53.5				79,834
Colorado	3,395,263	1,892,021	1,885,276	93.1	239,486	239,470	11.0				1,270,518
Connecticut	1,418,709	288,605	279,273	2.9	497,298	461,563	5.8	297,181	297,181	8.9	380,693
Delaware	900,310	390,511	387,034	45.0	475,574	377,916	21.9				135,360
Florida	2,597,144	1,181,942	1,178,106	47.3	1,287,266	1,287,266	51.3	66,957	66,957	.4	64,815
Georgia	4,988,967	449,489	444,688	29.0	782,908	782,908	44.8	339,369	339,369	31.4	3,422,002
Idaho	2,222,747	2,111,190	2,043,061	173.7	135,387	135,387	9.5	19,658	19,658	2.4	24,642
Illinois	8,694,009	7,038,863	6,999,745	382.7	1,637,140	1,637,140	88.4	36,000	36,000	.1	21,123
Indiana	4,941,255	2,001,009	1,776,314	76.5	3,065,029	3,065,029	152.1	37,924	37,924	6.3	61,987
Iowa	4,991,664	2,550,516	2,449,491	322.3	2,673,790	2,520,723	198.4	37,723	21,450	2.9	
Kansas	4,994,975	2,155,310	2,154,850	226.1	2,848,316	2,831,762	149.0	6,600	6,600	.5	1,763
Kentucky	3,726,271	2,388,502	2,379,085	287.5	827,502	827,502	56.3	295,828	295,819	5.9	223,865
Louisiana	2,890,429	1,039,962	884,805	59.3	1,855,385	1,654,283	105.8	230,428	192,802	9.5	158,539
Maine	1,676,799	1,225,576	1,224,205	52.6	382,292	382,292	18.5	52,100	52,100	1.7	18,202
Maryland	1,750,738	261,807	261,807	14.6	629,100	599,745	12.3	549,422	449,556	14.2	439,629
Massachusetts	3,262,885	117,754	117,754	1.1	2,640,216	2,286,856	16.9	141,900	141,900	.4	716,375
Michigan	6,301,414	6,018,500	5,957,970	283.0	197,071	197,071	6.4	190,850	145,850	3.3	523
Minnesota	5,277,145	5,108,678	4,328,352	807.9	1,225,185	821,200	93.3	137,137	120,248	2.3	7,345
Mississippi	3,457,552	1,703,768	1,699,701	123.2	1,476,644	1,475,275	91.1	220,759	220,759	17.8	61,817
Missouri	6,012,652	3,401,605	3,370,237	695.8	2,265,859	2,149,902	80.3	597,073	429,968	1.7	62,544
Montana	3,676,416	3,388,933	3,388,267	185.1	244,036	236,066	10.2				52,084
Nebraska	3,870,739	2,232,480	2,139,164	240.1	1,315,462	1,313,958	117.6	117,894	117,894	12.2	249,723
Nevada	2,243,074	1,758,455	1,704,805	79.4	266,225	266,225	12.0	21,998	21,998	.6	250,046
New Hampshire	945,225	576,606	551,621	24.6	257,992	255,249	9.8	36,688	36,583	.5	101,772
New Jersey	3,129,805	652,052	652,052	14.0	2,218,278	2,202,123	15.1	194,056	185,087	4.7	90,543
New Mexico	2,871,397	2,081,276	2,080,572	158.4	605,168	605,168	34.8	93,636	93,636	5.2	92,021
New York	11,046,377	6,822,509	6,535,331	128.8	4,295,350	4,167,450	39.0	328,700	328,700	2.5	14,895
North Carolina	4,720,173	1,816,868	1,816,868	117.6	2,664,760	2,601,571	159.9	177,371	141,431	10.0	160,303
North Dakota	2,867,245	1,361,931	1,360,193	206.0	1,150,996	1,147,560	99.6	159,611	159,611	20.2	199,880
Ohio	7,670,815	2,733,841	2,701,278	106.8	3,779,307	3,700,911	132.4	1,123,660	1,120,130	58.2	148,496
Oklahoma	4,580,670	2,088,417	2,077,953	185.1	1,651,715	1,650,119	171.0	618,286	606,299	36.3	246,299
Oregon	3,038,642	2,054,423	2,035,590	149.3	1,161,327	799,892	8.0	69,992	69,992	9.5	133,169
Pennsylvania	9,347,797	1,552,018	1,490,359	77.4	2,140,556	2,090,718	56.2	1,966,721	1,960,907	62.2	3,805,813
Rhode Island	989,208	990,131	979,535	18.8				9,673	9,673		
South Carolina	2,702,012	846,994	800,528	84.8	1,406,463	1,357,932	131.8	257,317	244,009	16.3	299,543
South Dakota	2,976,454	1,902,992	1,902,393	372.4	797,827	797,827	91.1	106,870	106,870	18.2	169,364
Tennessee	4,192,460	2,079,089	2,072,209	85.3	994,961	994,961	38.4	511,050	511,050	18.9	614,240
Texas	11,989,350	9,734,549	8,834,417	894.1	3,290,763	3,011,798	217.8	188,047	89,975	10.0	53,161
Utah	2,067,154	1,505,860	1,369,436	158.1	545,041	513,678	31.6	90,221	90,221	3.5	93,819
Vermont	924,306	842,732	741,059	20.5	178,368	142,065	1.2	33,020	19,910	.4	21,272
Virginia	3,652,667	2,736,504	2,661,344	860.1	690,775	677,701	155.1	135,181	135,181	27.6	178,442
Washington	3,026,161	2,509,038	2,278,785	157.7	892,267	747,376	6.9				
West Virginia	2,231,412	396,480	393,276	22.0	1,680,051	1,679,711	67.6	92,170	61,438	.9	96,987
Wisconsin	4,823,884	4,798,904	4,261,018	312.8	699,752	542,287	30.4				20,579
Wyoming	2,219,155	1,598,113	1,598,095	123.1	601,745	582,876	17.0				38,184
District of Columbia	949,496	930,398	930,398	8.6	25,600	362	.2				18,735
Hawaii	926,033	244,040	228,809	4.0	401,856	395,297	4.9	286,422	285,884	8.4	16,044
TOTALS	195,000,000	113,831,069	109,211,247	9,204.0	65,068,041	61,934,135	3,116.9	9,964,822	9,359,841	447.9	14,494,777

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF DECEMBER 31,1936

STATE	APPORTIONMENT	COMPLETED		NUMBER			UNDER CONSTRUCTION		NUMBER			APPROVED FOR CONSTRUCTION		NUMBER			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 1,360,021	$ 1,360,021	20		4	$ 2,409,673	$ 2,409,673	28			$ 44,867	$ 44,867	1		8	$ 220,057
Arizona	1,256,099	618,960	614,725	7			566,261	554,816	6								86,558
Arkansas	3,574,060	1,271,375	1,267,250	29	4		1,651,166	1,648,268	21	2		487,346	486,641	7		29	171,901
California	7,486,362	3,494,543	3,373,754	21	7		3,919,677	3,796,182	23	1							316,426
Colorado	2,631,567	1,076,063	1,055,063	20			847,708	847,699	7	1		284,733	284,732	3			444,073
Connecticut	1,712,684						719,457	647,379	4	1	1	261,044	261,044		2		804,261
Delaware	418,239						143,486	120,000	1								298,239
Florida	2,827,883	994,679	992,948	7	5		1,276,024	1,275,101	20	1		228,200	228,200	2			331,634
Georgia	4,895,949	12,090	12,090	1			422,893	422,893	8	2		481,243	481,243	16			3,979,723
Idaho	1,674,479	896,716	893,543	14	1	1	374,017	373,903	6		1	25,265	25,265			15	381,767
Illinois	10,307,184	2,912,631	2,912,094	40			5,626,077	5,455,790	28	5		1,901,700	1,901,700	8	2		37,600
Indiana	5,111,096	1,034,272	1,034,272	16	3		3,836,817	3,713,698	27	8		399,720	363,120			162	6
Iowa	5,600,679	1,696,581	1,649,719	45	6		3,668,194	3,632,948	58	3		371,061	255,980	4		8	62,032
Kansas	5,246,258	774,057	774,057	11		3	4,490,655	4,425,590	45	1		46,611	46,611	2		1	
Kentucky	3,672,387	265,336	265,336	7	1		2,463,277	2,173,545	13	2		184,391	184,391	3	3		1,049,115
Louisiana	3,213,467						1,447,148	1,447,148	14	1		966,512	922,046	8	3		844,272
Maine	1,426,861	497,560	497,227	12		2	584,695	584,103	8			77,464	77,464	1			268,066
Maryland	2,061,751	274,706	274,706	2	3		595,123	595,123	3		11	644,080	621,611	2	2	8	570,311
Massachusetts	4,210,833	498,005	498,005	4	2		2,450,301	2,450,301	19	1		249,991	249,991	1			1,012,536
Michigan	6,765,197	3,167,975	3,123,475	33	4		3,602,197	3,602,197	12	4							39,525
Minnesota	5,395,441	2,846,593	2,715,679	60	9	38	2,509,840	2,323,459	26	3	3	58,428	58,428		1	1	297,875
Mississippi	3,241,475	617,911	617,911	18	3	1	1,943,378	1,943,378	35			33,400	33,400	1		3	646,786
Missouri	6,142,153	308,981	308,981	6			5,695,929	5,499,685	46			367,251	253,300	1		2	80,187
Montana	2,722,327	2,475,015	2,475,015	35	6		178,582	178,582	2								68,730
Nebraska	3,556,441	1,524,429	1,523,107	57	1	1	1,523,787	1,523,787	21	1	5	433,559	433,559	5	1	19	75,988
Nevada	887,260	690,198	690,198	9	1		211,658	193,432	1			3,630	3,630			5	
New Hampshire	822,484	341,749	341,748	3	3		160,490	160,490	4	1	1	264,177	264,132	3			56,114
New Jersey	3,983,826	233,331	233,331	1	2		2,305,294	2,294,249	16			305,279	305,279	2	2		1,150,967
New Mexico	1,725,286	665,807	665,807	12			1,062,169	1,059,479	7	1							
New York	13,577,189	2,070,973	2,066,173	11	8		9,688,651	9,432,605	29	30		334,720	334,720		5		1,743,691
North Carolina	4,823,958	676,700	676,700	11	7		2,539,248	2,523,748	27	9	46	780,180	780,180	10	1	15	843,330
North Dakota	3,207,473	434,386	434,386	14			1,849,657	1,848,657	29	3		657,820	657,820	15	1		266,610
Ohio	8,439,897						4,768,797	4,543,193	29	5		3,138,670	2,976,612	23	2	3	920,092
Oklahoma	5,004,711	1,234,711	1,234,711	26	2		1,892,426	1,892,426	22	2		522,967	522,967	6	4		1,354,607
Oregon	2,334,204	841,868	841,329	8	5	2	1,528,728	1,447,128	8	1		34,950	34,950	1			10,798
Pennsylvania	11,483,613	674,465	607,001	21	1		6,896,137	6,360,721	44	13	9	2,141,769	2,031,469	7	3		2,484,423
Rhode Island	699,691	398,464	398,464	2	1		277,805	276,739	2	1							24,488
South Carolina	3,059,956	482,776	475,124	12	2	3	1,400,825	1,389,482	25	7		242,803	242,803	1		51	952,547
South Dakota	3,249,086	630,112	630,112	18	1	11	1,556,719	1,556,719	37	2	14	289,025	289,025	8	1	6	773,230
Tennessee	3,903,979	358,211	358,211	6	1	10	1,547,863	1,547,863	25	1	3	720,356	720,356	7	1	9	1,277,550
Texas	10,855,982	3,066,914	3,066,913	52	9		6,673,820	6,667,443	75	4		679,547	679,541	2	1	176	442,086
Utah	1,230,763	87,218	85,828	1	1		1,109,086	1,092,438	16			2,400	2,400			1	50,096
Vermont	729,857	479,951	474,639	7	5	9	191,630	176,930	1	1	3	58,600	29,000	2		2	49,288
Virginia	3,774,287	1,321,875	1,251,010	26	5		953,598	914,599	12	7		501,186	501,185	12	2	11	1,107,493
Washington	3,095,041	869,998	865,167	15	3	5	1,966,931	1,966,506	8	8	1	9,967	9,967			3	253,401
West Virginia	2,677,937						1,332,633	1,332,631	17	2		371,232	371,232	4	1	4	974,073
Wisconsin	5,022,683	1,896,054	1,867,957	24	4		3,077,522	2,979,068	13	3							175,658
Wyoming	1,360,841	355,507	355,400	5			758,835	723,832	7								281,609
Dist. of Columbia	410,804						425,564	396,804	3								14,000
Hawaii	453,703						522,380	453,703	5								
TOTALS	196,000,000	46,429,767	45,859,187	749	116	90	107,644,828	104,876,133	943	138	98	18,606,144	17,970,861	168	38	542	27,293,819

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF DECEMBER 31,1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 15,525,961	$ 8,301,392	$ 3,713,718	770.0	$ 284,709	$ 52,665	$ 232,044	6.9		$ 285,822	1.5	$ 16,076	$ 28,258
Arizona	5,211,960	2,641,935	8,981,820	5,204,512	2,605,035	542.8	12,500		12,500					7,448	24,400
Arkansas	6,748,335	3,428,049	10,947,995	6,631,484	3,347,140	619.9	114,076	70,019	43,836	3.4	$ 39,772	27,086	14.0	7,059	9,988
California	15,607,354	7,932,206	30,585,103	15,582,422	7,769,804	758.7	115,898		115,836					24,932	46,567
Colorado	6,874,530	3,486,006	11,258,083	6,870,681	3,441,857	639.0	6,619		6,619					3,849	37,530
Connecticut	2,865,740	1,454,868	4,514,512	2,758,269	1,312,770	74.0	59,618	59,618		.1				47,854	142,098
Delaware	1,819,088	923,395	2,680,794	1,818,804	815,188	128.3	109,467		105,524	1.6				284	2,682
Florida	5,231,834	2,661,343	8,910,496	5,175,534	2,344,563	305.6	323,079		298,765	4.0	56,300		.5		18,016
Georgia	10,091,185	5,113,491	13,271,065	9,296,628	3,225,883	750.8	1,007,623	408,689	598,934	74.3	84,072	160,706	3.6	301,796	1,127,968
Idaho	4,486,249	2,277,486	7,024,481	4,416,568	2,185,517	500.5	54,193		52,034	.1	60,772	1,886	.9	8,909	38,050
Illinois	17,570,770	8,921,401	26,113,952	17,182,552	7,893,567	712.3	1,420,426	305,409	987,756	11.2	37,300	7,100	12.8	45,509	32,978
Indiana	10,037,843	5,088,963	15,388,828	9,896,355	4,746,885	474.1	332,046	129,083	202,963	10.6		58,728		12,405	80,388
Iowa	10,055,660	5,118,361	15,455,458	10,055,161	4,797,361	1,222.2	340,072		321,000	5.1	499				
Kansas	10,089,504	5,117,675	15,428,707	10,089,600	4,996,100	1,132.3	126,993		61,887	13.1				4	59,688
Kentucky	7,517,359	3,818,311	12,036,112	7,507,142	3,571,866	811.4	216,151		216,151	4.2	8,569	21,599		1,649	8,694
Louisiana	5,828,591	2,963,932	9,097,185	5,787,557	2,647,424	259.5	258,115		194,632	11.5		72,999	.1	41,034	48,876
Maine	3,369,917	1,711,586	5,252,649	3,346,879	1,676,308	193.5	15,000	15,000				26,540	1.4	8,038	8,738
Maryland	3,564,527	1,810,058	5,554,198	3,477,038	1,010,456	148.5	162,147		161,772	5.3		285,453	7.3	87,489	352,376
Massachusetts	6,597,100	3,350,474	10,289,929	6,552,734	3,079,706	115.5						91,944	.1	44,366	173,824
Michigan	12,736,227	6,452,568	20,647,283	12,736,227	6,261,188	766.9	144,388		144,388	1.2		40,000	.4		6,992
Minnesota	10,656,569	5,425,551	16,203,961	10,514,422	4,857,905	1,641.9	367,062	58,110	263,294	7.2		34,800	.6	84,037	269,552
Mississippi	6,978,675	3,540,227	12,720,298	6,759,456	2,995,555	723.3	630,562	165,697	464,865	20.8	3,960	41,503	1.9	49,563	38,304
Missouri	12,180,306	6,173,740	18,133,563	12,107,561	4,923,651	1,441.2	1,130,984		1,127,050	6.4		62,100		72,745	60,939
Montana	7,439,748	3,769,734	11,799,994	7,425,476	3,701,189	1,058.4	56,546		56,546					14,272	11,999
Nebraska	7,828,961	3,964,364	12,837,672	7,813,593	3,613,533	1,018.4	272,820		265,494	27.7		63,537	5.9	15,368	21,800
Nevada	4,545,917	2,302,356	7,065,551	4,545,917	2,268,591	758.8	25,004		25,004			1,650			7,111
New Hampshire	1,909,839	969,462	3,003,046	1,904,951	950,495	78.3	4,174		4,174					4,888	14,793
New Jersey	6,346,039	3,220,879	9,096,708	6,045,652	2,452,252	85.9	1,118,813	120,518	564,155	10.3	82,145	108,487	.6	97,724	95,985
New Mexico	5,792,935	2,941,700	8,783,298	5,731,884	2,816,300	743.9	107,130		107,130	5.9		2,695		61,051	15,575
New York	22,330,101	11,327,921	39,097,150	21,774,925	10,156,383	821.1	1,459,830	399,810	963,899	2.7	127,947	119,856	1.3	27,419	87,784
North Carolina	9,522,293	4,840,941	14,957,059	9,210,800	4,519,894	1,345.8	349,990	291,910	58,080	15.3		200,000	4.3	19,582	62,967
North Dakota	5,804,448	2,938,967	8,635,442	5,617,145	2,260,751	2,127.0	230,303	106,183	124,120	16.3	15,703	153,680	27.9	65,418	400,415
Ohio	15,484,592	7,865,012	24,589,953	15,352,665	7,396,005	787.7	429,258	73,790	326,551	8.3	34,023	87,639	4.2	24,114	54,817
Oklahoma	9,216,798	4,685,180	14,623,860	9,213,572	4,313,159	805.5	105,855		105,855	1.1		174,301	.2	3,226	91,865
Oregon	6,106,896	3,097,814	9,901,295	6,037,198	2,940,828	468.0	75,530	11,308	64,222	.8		26,981		58,391	65,783
Pennsylvania	18,891,004	9,590,788	28,747,852	18,514,079	8,746,329	1,052.8	496,820	76,678	377,896	3.8	151,626	149,500	3.9	148,620	317,063
Rhode Island	1,998,708	1,014,572	3,144,150	1,998,708	1,012,094	89.1									2,478
South Carolina	5,459,165	2,770,954	7,999,369	5,239,181	2,446,499	618.2	287,505	160,231	127,073	8.7	45,034	122,701	2.8	14,719	74,680
South Dakota	6,011,479	3,047,643	9,275,815	5,839,840	2,859,784	1,571.5	207,934	77,600	130,334	27.0		12,161	8.6	94,039	45,364
Tennessee	8,492,619	4,302,991	13,562,878	8,490,706	4,030,678	492.3	178,372		178,372	4.0		79,417	5.9	1,913	14,525
Texas	24,244,024	12,291,253	37,900,154	24,189,662	11,788,904	2,779.9	180,441	2,797	177,644	.1	12,000	199,801	9.3	39,564	124,904
Utah	4,194,708	2,132,691	7,337,875	4,150,917	2,094,401	590.9	70,718	32,292	38,290					1,500	
Vermont	1,867,573	948,007	3,165,570	1,867,452	942,669	141.0								121	5,337
Virginia	7,416,757	3,765,387	11,659,062	7,300,754	3,410,560	614.5	296,615	84,042	206,941	30.5	7,035	59,917	3.6	24,925	87,970
Washington	6,115,867	3,106,412	9,399,840	6,112,042	3,027,370	302.7	46,596		46,596			14,823	.3	3,825	17,622
West Virginia	4,474,234	2,280,335	6,261,183	4,313,749	1,636,742	211.1	591,626	83,534	460,028	11.4		66,425	.7	76,951	117,140
Wisconsin	9,724,881	4,941,837	15,144,406	9,720,705	4,898,836	619.7	2,668		2,668		4,176	2,720			37,613
Wyoming	4,501,327	2,287,712	6,889,603	4,451,922	2,228,700	1,037.7	5,781	5,780		.3		21,300		43,624	37,712
District of Columbia	1,918,469	973,842	2,887,584	1,918,469	968,979	22.3									4,863
Hawaii	1,871,062	949,778	2,680,982	1,857,812	264,953	51.1	650,838		646,859	4.8		14,000		13,250	23,966
TOTALS	394,000,000	200,000,000	626,769,784	388,718,754	181,966,325	35,025.8	14,482,895	2,790,763	10,669,781	366.0	770,933	2,899,857	124.6	1,719,550	4,464,037